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CONTROL OF MICROSCOPIC ORGANISMS IN PUBLIC WATER SUPPLIES, WITH PARTICULAR REFERENCE TO NEW YORK CITY.

BY FRANK E. HALE.*

[*Read February 12, 1930.*]

Mt. Prospect Laboratory was founded in 1897. The original reason for its existence was not sanitation, but the control of tastes and odors caused by microscopic organisms. Previous to the establishment of this laboratory, the citizens of Brooklyn had risen in arms because of the unsatisfactory condition of the water supply, and George C. Whipple was called from Massachusetts to assist in searching out and alleviating the trouble, which was found to be a matter of *Asterionella* growing in Mt. Prospect Reservoir. Since that time much has been learned and it is no more than proper that after these many years we should report back to the mother state such progress as we have made in controlling microscopic growths and the odors and tastes associated with them.

By-passing Reservoirs. In the early days growths of 10 000 to 20 000, or more, units† of troublesome organisms were not uncommon and undoubtedly furnished food for abundant growths of pipe-moss in the mains. The only remedy available was to shut off the troublesome reservoir and allow it to stand idle until the organisms were sufficiently reduced in numbers; but even this procedure caused its troubles. Mt. Prospect Reservoir had a by-pass main installed so that the influent gate could be closed and the reservoir allowed to ride on the service through the effluent pipe while the organisms were dying out. On one occasion, the pipe-moss was dislodged by reversal of current in the by-pass, and all the house services in the territory served became plugged so tightly with the moss that no water could pass. As a remedy the fire engines were called upon to pump from the hydrants and draw the growths away from the taps. This was cheaper than sending plumbers to every house to force the growth back, and had the additional advantage of drawing the growth out of the mains.

Use of Copper Sulphate.

Early Experiments. As soon as Moore and Kellerman's bulletin on copper sulphate was issued we were on the job trying out the effectiveness

*Director of Laboratories, Department of Water Supply, Gas and Electricity, New York, N. Y.
†Areal standard units are referred to throughout this paper.

of this chemical. Our first experiments were made on a pond in Prospect Park. A solution of copper sulphate was sprayed over the entire surface, and we had the satisfaction, despite skepticism, of entirely destroying a heavy growth of *Clathrocystis*. To prove that the change of color of the growth indicated a union of copper with the organisms we evaporated a gallon of the water and after destroying the organic matter, electrolyzed the nitric-acid solution of the residue and recovered substantially all the copper which had been applied. Other experiments were then conducted, first on watershed ponds and later on distribution reservoirs. Much of this early work was reported in the symposium on copper sulphate held by the NEW ENGLAND WATER WORKS ASSOCIATION at its convention in New York City in 1905.

Lack of Development of Resistance. One of the questions raised at that time was whether the organisms became resistant to copper sulphate so that conditions would eventually become worse. This question has been quite definitely answered in the negative by the experience of many years.

Relation to Health. Another important question debated was that of possible deleterious effect of the copper salts upon the health of the water user. This likewise seems definitely answered in the negative. There is many times more copper in milk and other foods than in a water supply after treatment, and recently important work has been done to prove that copper is beneficial in pernicious anemia. The metal is normally present in the human body and at worst is not an accumulative poison. Several years ago experimental work was published indicating the possibility of cirrhosis of the liver being caused by copper sulphate. This idea has been refuted by more recent work. At the time the idea was propounded I charted the number of deaths from cirrhosis of the liver occurring in New York City (supplies chlorinated and copper sulphate used frequently), Chicago (supply chlorinated and probably no copper sulphate used), and Boston (supply not chlorinated) over a long period of years before and after copper sulphate was first used. Instead of an increase, I found a marked drop in deaths from cirrhosis of the liver equal to the drop in typhoid fever. This decrease followed the enactment of prohibition. In order to eliminate any possible effect of chlorination, Boston was included in the study.

METHODS OF APPLICATION.

Spraying. Many ways of adding copper sulphate to water supplies have been developed. Spraying a solution over the surface was probably the earliest method tried. It is rarely used now. The only place where it has been employed to any extent, to my knowledge, is by Domogalla* at Madison, Wis. There a large pressure tank set on a scow has been used, and as much as 70 tons of copper sulphate a year have been applied. Gilkenson,† in Kansas City, in 1921 applied copper sulphate by spray to the

*Eng. News-Rec., Vol. 79, 1926, p. 950.
†Jour. Am. W. W. A., Vol. 8, 1921, p. 88.

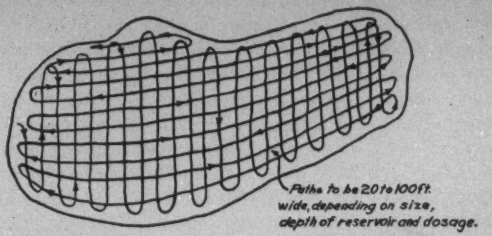
walls of a clear-water basin to destroy long filamentous growths of *Spirogyra*. He used a 5 per cent. solution of the chemical and found that one gallon would cover 125 sq. ft. The basin was lowered so as to expose the upper 6 ft. of wall surface. It was found necessary to repeat the spraying once in two months during the summer. One hour after application the walls were cleaned with a wire brush. The method required less copper sulphate than when the inflowing water was treated, since the latter required a dosage of 1 to 1½ p.p.m. N. L. Huff* states that *Cladophora* at times floats in great raft-like masses on the water surface and that it is readily killed by spraying a strong solution of copper sulphate on these masses, whereas regular dosage of the entire body of water would require ten times the usual dosage for most organisms.

Rowboats. The next development was the use of burlap bags, holding about 50 pounds each, which were dragged through the water from a rowboat. This method is still in common use. One man rows as fast as possible and another swishes the bags up and down and back and forth so as to prevent the chemical from dissolving too quickly while distributing it as widely as possible. Thorough distribution is important. I have seen a treatment fail entirely when the copper sulphate was distributed from the shore line, because a broken oar interfered with the use of the boat. Furthermore, if one treatment fails because of improper distribution or insufficient dosage, it does no good to follow up with the additional amount needed. The entire dose required must be reapplied. The use of rowboats is applicable to shallow bays and small bodies of water. The paths of the boat should triangulate the surface (Fig. 1).

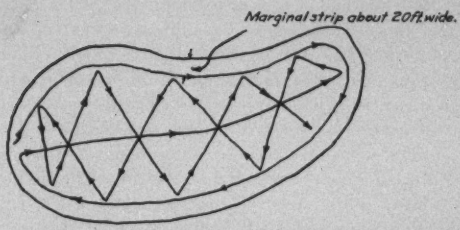
Launches. For large reservoirs the use of launches is necessary. A storage bin may be built across the center of the vessel to hold one or two barrels of the chemical. Burlap bags are suspended from both sides and are held open by two cross-bars. One man runs the launch and another shovels the chemical into the bags. The propeller helps to distribute the chemical as it dissolves. It is customary to travel parallel courses about 100 ft. apart and after covering the reservoir in this way in one direction to cover it again at right angles to the first direction (Fig. 1). The reservoir should be partitioned into areas by land sights, and the capacity, in m.g. for total depth, calculated for each area so that dosage may be correctly apportioned. Occasionally when organisms, such as the *cyanophyceæ*, and certain *protozoa* (*Synura* or *Uroglena*), predominate in the upper water strata, dosage may be based with success upon the upper 20 or 30 ft. of water. Figure 1 indicates the arrangement of courses of travel in treating large and small reservoirs. The arrangement of a launch equipped for carrying out the treatment is shown in Fig. 2.

It is surprising how effective crude treatments are. Reliance must be placed on wind, waves, diffusion and gravity to admix the streaks of treated water with the remainder. About 3 000 lb. of copper sulphate may be dis-

*Jour. A. W. W. A., Vol. 15, 1926, p. 501.



ADAPTABLE PARTICULARLY TO LARGE RESERVOIRS



ADAPTABLE PARTICULARLY TO SMALL RESERVOIRS

FIG. 1.— METHODS OF DOSING RESERVOIRS WITH COPPER SULPHATE FROM A ROWBOAT OR LAUNCH.

FIG. 2.— LAUNCH EQUIPPED FOR APPLYING COPPER SULPHATE TO A RESERVOIR.

tributed in a day by a single launch when the weather is favorable. The usual time required in 1924 to treat some of the large Croton watershed reservoirs, allowing for weather conditions was as follows:

Reservoir.	Capacity. m.g.	Time. Days.
Sodom	5 243	4
Bog Brook	4 400	3
Croton Falls	14 865	8
Muscoot	5 705	3
Croton Lake	28 110	7

The extent to which treatment of these large reservoirs has been undertaken in recent years on New York City's watersheds is shown in Table 1.

TABLE 1.— TREATMENT OF LARGE RESERVOIRS WITH COPPER SULPHATE, NEW YORK CITY.

Date.	Reservoirs.	Capacity, Bil. Gals.	Copper Sulphate. Tons.	Organisms.
1922, Mar.	Kensico (portion).	10	3	*Synura.*
" Sept.	Kensico (portion).	7	2	*Synura.*
" Nov.	Kensico (portion).	10	3	*Synura.*
" Dec.	Kensico (entire).	38	19½	*Synura.*
1923, June–Oct.	Croton, Muscoot, Diverting Basin, Sodom, Bog Brook	44	16	*Anabaena, Dinobryon, Aphanizomenon, Tabellaria.*
" Dec. 8–30.	Kensico (entire).	38	20	*Synura.*
1924, Fall.	Kensico (portion).	23	10	*Synura.*
" May.	Middle Branch.	4	2½	*Tabellaria.*
" Oct.	Muscoot.	6	2½	*Aphanizomenon.*
" Nov.	East Branch.	10	2½	*Aphanizomenon.*
1925, July, Aug., Oct.	Croton Lake.	28	8	*Aphanizomenon and Synura.*
" May, Aug.	Muscoot.	6	5½	*Asterionella, Aphanizomenon.*
" Nov.	Kensico (portion).	18	8	*Synura.*
1926, Apr.–May.	Croton, Muscoot, Diverting Basin, Sodom, Bog Brook	44	15	*Synura* (100–1 300 units).
" Sept.	Muscoot.	6	4	*Aphanizomenon.*
" Nov.	Muscoot, Croton.	30	8	*Aphanizomenon.*
" Aug.	Middle Branch.	4	2	*Aphanizomenon.*
" Oct.	Titicus.	8	1½	*Coelosphaerium.*
" Sept., Oct.	Ashokan (very low).	16	5	*Synura.*
" Sept.	Kensico (portion).	8	11	*Synura.*
" Dec.	Kensico (entire).	30	14	*Synura.*
1927, Apr.	West Branch.	11	3	*Synura.*
" May.	Sodom.	5	2	*Synura.*
" Nov.	Kensico (portion).	4	2	*Synura.*
1928, Jan.	Kensico (portion).	18	5	*Synura.*
" Oct.	Kensico (portion).	30	13	*Synura.*
" Mar.	West Branch.	11	2	*Synura.*
" Nov.	Croton, Muscoot.	34	8½	*Aphanizomenon.*

Note: Dosage was based on 1 lb. per m.g. in every case, but in several instances on upper water only, 10, 20, 30, 50 or 75 ft. The first three depths were gaged on organisms floating in the upper water, the last two depths on depth of draft.

Aqueduct Continuous Dry Feed. On December 30, 1919, a new departure was made in the methods of treatment. On the Catskill Aqueduct between Ashokan and Kensico reservoirs, about two miles above Kensico, a treatment plant had been built by the Board of Water Supply for the purpose of adding alum to the water when high turbidity should demand it. The aqueduct was narrowed in this building to a width of 7 ft., and large revolving brass screens were installed, turned by the flow of water acting against projecting vanes. The chemical was arranged to be fed through two 6-in. iron tubes which united to form a single tube ending in a hopper. The chemical was fed by a moving shutter, the stroke of which could be varied, together with the depth of chemical on the shutter. This equipment was now used to feed copper sulphate into the aqueduct water. Although the equipment was designed to handle many tons of alum a day, no great difficulty was experienced in feeding 400 to 600 lb. of copper sulphate a day. The treatment was first used for *Asterionella* and demonstrated that the same dosage was effective in this manner, fed continuously to a known flow of water, as when distributed over a reservoir by boat. The great advantage was that the treatment could be made in the winter when ice was on the reservoir, and the seeding of Kensico from Ashokan Reservoir thus prevented. That this organism was killed, was shown by production of the characteristic odor, quick settling of the shells in a bottle and disintegrated appearance of the coloring matter under the microscope. While treatment was successful, the very first use of copper sulphate destroyed the iron tubes at the points where the chemical struck the water. In subsequent treatments they were replaced by a wooden flume, and the chemical was fed to a floating, perforated wooden box. This arrangement worked equally well. The first winter treatment for *Asterionella* was 0.20 p.p.m. Later a spring treatment demonstrated that 0.12 p.p.m. was equally effective in the warmer water. Some of the organisms that have been controlled by this method are *Asterionella*, *Tabellaria*, *Anabaena*, *Coelosphaerium*, and *Synura*, especially the latter. The extent to which this manner of treatment has been employed is shown in Table 2. The reduction in automatic treatment shown in this table since 1924 will be referred to again later.

TABLE 2.— AUTOMATIC CONTINUOUS TREATMENT IN CATSKILL AQUEDUCT.

Year.	Periods.	Total Time.	Copper Sulphate.	Organism.
	Number.	Months.	Tons.	
1920	5	3	24	*Asterionella.*
1921	2	1	4½	*Asterionella, Synura.*
1922	4	5	38	*Synura.*
1923	3	6	42	*Synura.*
1924	3	5	33	*Synura.*
1925	1	1	9	*Synura.*
1926	1	1½	11	*Anabaena, Coelosphaerium.*
1927	0	0	0	
1928	1	¼	2	*Synura.*

Automatic continuous treatment has been used at many points, particularly upon the Croton Watershed, sometimes in reservoir effluents, at other times in small streams. Two of the more important large treatment devices will be described. Both these were designed by T. DeL. Coffin, Assistant Engineer in Charge of Sanitation, Croton Watershed. I am indebted to him for much of the description that follows.

Aqueduct Continuous Solution-Feed Equipment. The first of these devices is illustrated in Fig. 3 and is employed for Croton aqueduct water at the Croton Lake gatehouse. After treatment, the water flows 23 miles

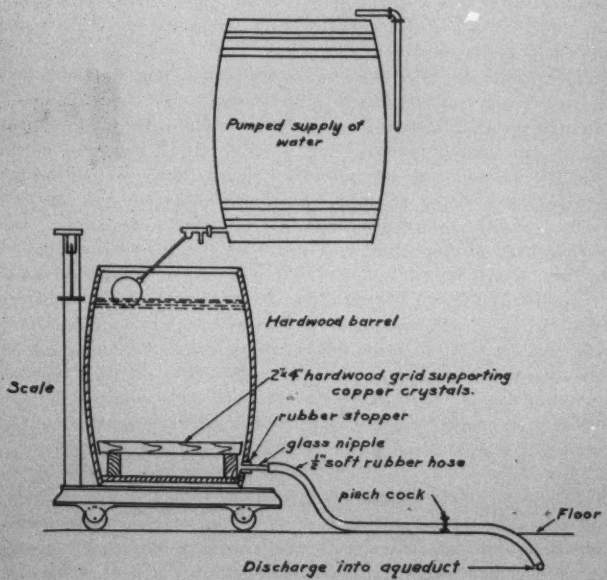


FIG. 3.— SOLUTION-FEED DEVICES FOR DOSING NEW CROTON AQUEDUCT WITH COPPER SULPHATE.

to Jerome Park Distributing Reservoir and is chlorinated in transit at Dunwoodie, 19 miles distant. This is important as the chlorine helps to destroy the taste and odor produced by the destruction of the organism by the copper sulphate. By this equipment the chemical is applied as a practically saturated solution, and the application is very uniform. The amount of chemical used has been 300 to 400 lb. per day. A barrel is kept constantly full of water from a supply controlled by a float valve. Within the barrel, raised above the bottom, is a slatted compartment into which the predetermined amount of copper sulphate is thrown hourly. From the bottom of the barrel the solution is discharged through rubber tubing, ½-in. diameter,

into the aqueduct water at the most turbulent point. The rubber tubing is slipped on to a small piece of glass tubing inserted in a rubber stopper. The flow is regulated by a pinch-cock. The barrel is set on scales so that the weight of chemical delivered can be checked. A few trials establish a uniform rate of solution and application. The float which regulates the flow of water into the barrel is constructed of glass. The other materials, copper, hardwood, and soft rubber, resist any corrosive action of the copper sulphate. The amount of water used varies with temperature and other conditions from about 1¼ to 2½ gal. per pound of chemical dissolved. The least amount of water that will dissolve the required amount of chemical is used, since this approaches a saturated solution irrespective of the amount of copper sulphate in the hopper.

This equipment was first used several years ago for the control of *Aphanizomenon*, but without discernible result even though a dosage of 1 p.p.m. was used. A few weeks ago, treatment with 0.25 p.p.m. failed again for the same organism. Both these treatments were in the winter season. Yet *Aphanizomenon* is readily killed by reservoir treatment when employing doses of 0.12 p.p.m. that are sometimes based on the upper 30-ft. volume, because this organism floats in the upper water strata. On the other hand the solution equipment operates well in destroying *Synura*. In 1928, from March 8 to May 12, eleven tons of copper sulphate (0.24 p.p.m.) were applied. Between March 8 and 16 only 41 per cent. reduction of *Synura* was noted. In consequence, on March 22, the point of application was moved about 5 ft. to where the water churned more vigorously. Better results were immediately obtained. After March 30, no more *Synura* were observed in the water at Dunwoodie before chlorination.

Float Continuous Dry-Feed Equipment in Lake. The second device has been employed at Muscoot Dam. Croton Lake is about 16 miles in length and is divided about midway by the submerged Muscoot Dam which has a spillway about 1 000 ft. long. There are 304 sq. miles of drainage area above it and only 71 below. Of the area above, all but about 70 sq. miles are controlled by the dams of the upper reservoirs, and growths may be controlled either at the dams or by reservoir treatment. In the winter, treatment is possible at the dams only. Muscoot Reservoir is a very shallow basin, and algæ develop profusely. To control these organisms, barrels were first set upon the crest of Muscoot Dam. These were weighted down with stones after small holes had been drilled through the lower portion of the barrels. A predetermined dose of copper sulphate was placed in each barrel. By trial it was possible to obtain a rather uniform dose in this way. Unfortunately, however, there was no ready means for holding the barrels in place. As a result a slight freshet washed them away.

The next arrangement was as follows. From the gatehouse on the southerly shore to a point on the northerly shore the distance is about 600 ft. across the water. Owing to the fact that the flow from 304 sq. miles passes over the dam, ice does not form immediately below the dam even in

severe weather. A cable composed of three twisted telephone wires was, therefore, suspended from the gatehouse over the water to a point high up on the opposite shore. To this cable 14 floats were attached at regular intervals. There was a hole in the bottom of each float. Into each a predetermined amount of copper sulphate was placed night and morning. The depth of submersion largely determined the rapidity of solution.

Growths in upper Croton Lake have been held in check with this equipment, although no definite study of the effectiveness of the method has been made. In 1924, before the floats were installed, *i.e.*, with the barrels on the dam, six tons of chemical were applied between February 12 and March 11 to control *Synura*. In 1925 with the floats in operation, treatment was applied between February 7 and 11 and October 2 and 31 using two tons of chemical for *Synura*, *Uroglena* and *Aphanizomenon* at a rate of 1 lb. per m.g. of estimated flow.

Some of the difficulties encountered in this method of dosage are due to the fact that the cable changes length with temperature and changes shape with variations in chemical loads upon the float and that wind produces various tensions on the different floats so that equal depth is not maintained and some bands may at times be tipped over; winds also break off large cakes of ice which bump against the floats. To some extent these difficulties were overcome by attaching the containers to large blocks of wood somewhat after the nature of a catamaran. This does much to obviate the action of wind, waves and ice. By having each float relatively heavy, furthermore, the load of copper sulphate does not have so much influence in changing the shape of the cable so that submergence of each dose remains fairly constant and hence the rate of solution fairly uniform. It is not an easy task to maintain this treatment in winter, since hours of daylight are relatively short so that for some 16 hours out of the 24 the floats receive no attention. Also it is difficult to pick men sufficiently versed in boatmanship to distribute the chemical during periods of storm and high wind.

Holes in Ice. Treatment through holes in the ice has been tried at times. It has been successful on very small reservoirs but is extremely tedious and ineffective on large reservoirs. Holes have been cut at 200-ft. intervals in checkerboard fashion, but the heavy solution of copper sulphate placed in them sinks to the bottom without diffusing. The containers freeze into the ice, and it is difficult to renew the dose. Because of cost, difficulty of handling and general ineffectiveness, this method has apparently been abandoned. The winter organisms causing most trouble, *Synura* and *Uroglena*, grow under the ice and the chemical does not reach them. Crystals have been scattered over the ice in the spring before the ice goes out, but this is a most uncertain treatment and not available when treatment is needed most.

The most successful and interesting treatment through the ice that I recall is described by G. R. Taylor.* It was used in 1924 in Brownell

*Jour. Am. W. W. A., Vol. 12, 1924, p. 307.

Reservoir supplying the city of Carbondale, Ill. Elaborate measures were taken to distribute the chemical in this case. Although the lake was one mile long and contained 850 m.g., only the lower portion (130 m.g.) near the dam and intake, separated by a sandbar, was treated. The organism was *Synura* (*Dinobryon* was also mentioned but was present in too small an amount to be objectionable). Copper sulphate to the extent of 450 lb. (3½ lb. per m.g. or 0.42 p.p.m.) was applied. Holes were cut every 25 ft., *i.e.*, over 400 in all. The ice was 18 in. thick, and the temperature was down to zero on two mornings, adding to the difficulties. Steam was furnished by a portable boiler, and one pound of chemical was dissolved at a time in a wooden pail. This solution was added to a 45-gal. barrel, pumped half full with water from the reservoir, mixed, and pumped under the ice at each hole through a 25-ft. hose attached to a long pole. The solution was distributed by means of the pole under the ice in all directions. The pump was a hand pump, with 3-in. suction and 3-in. discharge reduced to 1 in., mounted on a two-horse sled. Three 45-gal. wooden barrels were used as solution barrels and mounted on the sled. A fireman handled the steam boiler and dissolved the chemical. Another man carried the pails of solution to the sled. The sled crew consisted of a driver, four pump men, a hoseman and a foreman. The labor involved in cutting the holes through the ice is not mentioned. The treatment took 5 days, cost $385 in all and was immediately successful.

Partial Reservoir Treatment. Two or three days should always elapse before treated water reaches the consumer, in order that tastes and odors resulting from treatment may disappear. In the case of distribution reservoirs through which the water flows in about one week, the inlet half may be treated, and this treated water will displace the untreated portion.

TABLE 3.— TREATMENT OF CENTRAL PARK RESERVOIR, UPPER HALF.

	Asterionella. Standard Units per cc.	Total Organisms. Standard Units per cc.
Apr. 15, 1926, before treatment.	1 150	2 040
Apr. 22, 1926, after treatment (3 days).	1 350	2 100
Apr. 29, 1926, after treatment (10 days).	370	500

Note: The samples were taken from an effluent main.

This we have proved in several instances. In 1922 for the first time Central Park Reservoir was handled in this way. It contains about one billion gallons and provides between 7 and 10 days' storage since the Catskill supply was introduced, because less Croton water is used. In 1922, 0.5 p.p.m. copper sulphate was applied to the reservoir by rowboat, basing the dosage on the volume of the upper, or inlet, half treated. *Synedra*, to the

extent of 6 000 units, was destroyed. Later, 10 000 units of *Synedra* were destroyed by a dosage of only 0.36 p.p.m. Similarly 4 000 units of *Dinobryon* were controlled with 0.2 p.p.m. On April 19, 1926, *Asterionella* was treated with 0.25 p.p.m. The results shown in Table 3 are typical.

Last year (1929) heavy growths of *Synura* occurred in Central Park Reservoir. As this organism can move about, the method of dosage was varied. After the usual treatment of the upper half, a daily application of 100 lb. of copper sulphate was made in a central band about 200 ft. wide, representing roughly one day's flow. This was continued until the effluent end was free from *Synura*, both in the top and bottom water. This daily treatment prevented the *Synura* from traveling into the upper, previously treated, half of the reservoir.

Use of Copper Sulphate, New York City. The extent to which copper sulphate has been used in recent years by New York City to control microscopic organisms is shown in Table 4.

TABLE 4.— USE OF COPPER SULPHATE BY NEW YORK CITY.

Year.	Croton Watershed. lb.	Bronx Watershed. lb.	Catskill Watershed. lb.	Long Island Watershed. lb.	Distribution System. lb.	Total. lb.
1922	9 350	2 850	131 837	245	4 271	148 553
1923	32 335	85	85 040	905	2 519	120 884
1924	30 800	16 350	85 655	220	4 145	137 170
1925	37 485	3 025	35 750	1 350	4 327	81 937
1926	64 235	6 150	82 274	1 250	3 330	157 239
1927	17 400	11 250	4 500	1 490	1 115	35 755
1928	65 555	4 600	39 361	690	3 102	113 308

POINTS OF DRAUGHT.

Changing Point of Draught. With a system like New York City's, containing numerous reservoirs, many organisms are excluded by changing draught from one reservoir to another, from one basin to another in the same reservoir, and from one depth to another. Change of point of draught is a matter of frequent practice with New York City. At Ashokan Reservoir alone the draught is shifted half a dozen times during the year for one reason or another, not only to eliminate microscopic organisms but also to control turbidity. The draught is taken at times from the west basin, at times from the east basin and at times equally from both. At Croton Lake, similarly, draught may be shifted from the dam to the gatehouse at the old submerged dam, a distance of three miles.

Deep Draught. Many organisms float in the upper water strata, particularly the *cyanophyceæ*. In 1912 the policy of deep draught at Croton Lake was started in order to obtain water that was cooler, clearer and freer from microscopic organisms. Since then draught has been practically

continuous at a depth of 75 ft. The beneficial effect of this policy is shown in Table 5.

TABLE 5.— REDUCTION OF MICROSCOPIC ORGANISMS BY DEEP DRAUGHT.
Croton Supply — July, August and September.

Year.	Temperature. °F.	Micro-Organisms. St. Units per cc.	Reduction. Per Cent.
1911	72	2 836	..
1912	67	1 072	65
1913	65	677	75

Change of depth is practiced at Ashokan and many other reservoirs. Deep draught is the usual practice. The variations in the quality of water with depth in Kensico Reservoir are shown in Figure 4.

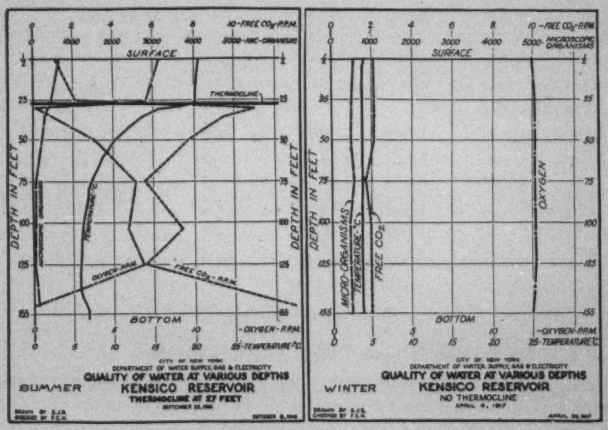


FIG. 4.

AËRATION.

Both the Ashokan and the Kensico aërators have been employed to assist in removing the taste- and odor-producing oils of microscopic organisms. The odor to leeward of the spray, when the wind is blowing, is marked when growths are prevalent. Certain delicate organisms such as *Uroglena*, *Synura*, *Dinobryon*, *Anabaena* and *Asterionella*, are partially disintegrated. In August, 1919, the Ashokan aërator was used to break up 1 500 units of *Dinobryon*. In March and April, 1918, and from October to December, 1919, the Ashokan aërator helped to hold *Synura* in check so

that it did not reach Kensico Reservoir in sufficient numbers to develop. In 1917, the two aërators controlled *Uroglena*. It is probably the splashing and jolting that produces the beneficial results. Only partial assistance may be expected from this source, however, as there is no assurance that the individual units are killed. The colonies are largely disintegrated. Since the difficulty experienced with *Synura* in the winter of 1921–1922, which received such wide publicity, the aërators have been considered chiefly as an aid to the removal of the tastes and odors produced by chemical destruction of the organisms.

Use of Chlorine.

Effect of Normal Dosage. Before the advent of chlorination, complaints about tastes and odors due to microscopic organisms were not generally received unless more than 1 000 units per cc. of a troublesome organism were present. Since chlorination began we have had to lower this figure to 500 units. It was not until 1919 that I traced complaints of fishy tastes to the effect of a normal dose of only 0.15 p.p.m. chlorine upon 700 units of *Tabellaria*. The increased taste is due in all probability to the destruction of the organism and the setting free of the distasteful oil. The taste is not intensified or changed in character but merely liberated by normal dosage. This has been noted with *Asterionella* (700 units), *Tabellaria* (700 units), *Dictyosphaerium* (700 units), *Volvox* (300 units), *Aphanizomenon* (700 units), *Ceratium* (500 units), *Dinobryon*, *Synura* (few units) and *Uroglena*.

Superchlorination. With the occurrence of the *Synura* trouble in 1921–1922, since the reservoirs were frozen and could not be treated with copper sulphate, recourse was had to chlorine to kill the organism. In addition superchlorination was experimented with on a plant scale and utilized to destroy the oil as well as the organism. Sir Alexander Houston's experiments in London with superchlorination to destroy medicinal tastes due to normal chlorination were available at the time and suggested our trial of superchlorination for microscopic organisms.* Our success at the time is well known and received sufficient publicity.

Dosage. With regard to dosage, experience then, and since, has shown that normal dosage of the Catskill water with 0.3 p.p.m. chlorine leaving a residual of 0.05 to 0.10 p.p.m. will take care of very small amounts of *Synura* (3 to 4 units up to possibly 25 units); a dosage of 0.5 to 0.7 p.p.m. with about 0.20 p.p.m. residual controls 50 to 100 units of *Synura;* 0.7 to 0.9 p.p.m. with a residual of 0.30 p.p.m. controls 200 units of *Synura*. Similarly *Uroglena* to the number of 2 000 units has been killed in Brooklyn water and its taste production destroyed by normal dosage of 0.5 p.p.m. with a residual chlorine content of 0.1 p.p.m. Six thousand units were killed with the same dosage but the taste was not destroyed. Yet the taste was not noticeable after 10 to 15 miles flow in the conduit. The same dosage in the

*I have since found a reference dated 1911 on the use of bleach to destroy algæ and diatoms.

same water has destroyed and deodorized 500 units of *Dinobryon*. Tables 6 and 7 are interesting in showing the destruction of organisms at two points on the Brooklyn Watershed caused by the regular normal dosage with chlorine with 0.10 p.p.m. residual as taken from the records for 1923.

TABLE 6.— EFFECT OF CHLORINATION UPON MICROSCOPIC ORGANISMS AT MILBURN CHLORINATION PLANT.

(Dosage 0.30 p.p.m., Residual 0.10 p.p.m.)

Date: 1923.	Taste Treated.	SYNURA.		UROGLENA.		DINOBRYON.	
		Raw.	Treated.	Raw.	Treated.	Raw.	Treated.
		St. Units per cc.		St. Units per cc.		St. Units per cc.	
Apr. 16	...	30	0	...	...	25	20(dead).
May 2	...	1 colony.	...	...	...	100	40
May 9	1 earthy.	20	1 colony (dead).	150	0	70	0
May 14	1 earthy.	75	2 colonies (dead).	75	0	50	0
May 18	1 earthy.	0	2 colonies (dead).	...	...	...	...
May 21	...	...	...	35	0	25	0
June 1	...	...	...	250	0	50	60
June 6	1 earthy.	...	...	75	0	50	50
June 11	1 earthy.	...	...	75	0	50	0
Oct. 3	...	...	...	...	...	25	0
Nov. 2	...	...	...	25	0	...	...
Nov. 23	...	...	...	200	0	...	...
Nov. 30	...	...	...	50	0	...	...
Dec. 14	...	1 colony.	0	15	0	...	...
Dec. 21	...	...	...	10	0	...	...

TABLE 7.— EFFECT OF CHLORINATION UPON MICROSCOPIC ORGANISMS AT SMITH'S POND CHLORINATION PLANT.

(Dosage 0.48 p.p.m., Residual 0.10 p.p.m.)

Date: 1923.	Taste Treated.	SYNURA.		UROGLENA.		DINOBRYON.	
		Raw.	Treated.	Raw.	Treated.	Raw.	Treated.
		St. Units per cc.		St. Units per cc.		St. Units per cc.	
Mar. 19	...	2 colonies.	0	20	0	500	0
Apr. 16	...	25	0	...	...	35	30(dead).
May 2	Sweet.	...	...	2 000	0	100	50
May 9	3 fishy.	...	...	6 000	0	...	...
June 11	Chlorine.	...	...	50	0	...	...
Dec. 21	...	...	...	15	0	...	...

Dosage with 0.5 p.p.m. of chlorine at Dunwoodie has so affected the organisms entering Jerome Park Reservoir, four miles below and with a

few days' storage capacity, that the effluent water showed 25 per cent. reduction against a previous experience of considerable increase. This reduction was noted with *Asterionella*, *Tabellaria*, *Melosira*, *Anabaena*, *Aphanizomenon*, and *Coelosphaerium*.

Several times, increased chlorination dosage has been purposely employed to control *Aphanizomenon* in the Croton supply. It was first tried in the spring of 1925. A dosage of 0.83 p.p.m. chlorine, residual 0.20 to 0.25 p.p.m., reduced the growth of 1 500 units by 50 per cent. after passage through Jerome Park Reservoir and prevented seeding Central Park Reservoir. Again in October, 1925, similar results were obtained with 0.72 p.p.m., residual 0.22 p.p.m. In the same way 1 350 units of *Asterionella* have been controlled by a dosage of 0.70 p.p.m. with 0.20 p.p.m. residual. In fact this method was employed again in January of this year (1930) for the same purpose due to complaints of scum on hot water in bath tubs caused by only 500 to 700 units of *Aphanizomenon* reaching the distribution system. It is astonishing how many complaints are received when so small a number of organisms is present, particularly from hotels and better-class apartments. The organism must concentrate in the hot water tanks and rise with the drawing of the water. Two samples taken from the top water of

TABLE 8.— EFFECT OF ASHOKAN CHLORINATION UPON AQUEDUCT TREATMENT WITH COPPER SULPHATE.

Year.	Chlorine Dosage.	Copper Sulphate in Catskill Aqueduct Continuous Dry Feed.		Organisms Treated.	Kensico Res. Effluent. Total Organisms.
	p.p.m.	Tons.	Months.		St. Units, per cc.
1922	...	38	5	*Synura.*	325
1923	...	42	6	*Synura.*	257
1924	...	33	5	*Synura.*	291
1925	0.17	9	1	*Synura.*	205
1926	0.21	11	1½	*Anabaena*, *Coelosphaerium.*	235
1927	0.21	0	0	....	200
1928	0.19	2	¼	*Synura.*	265
Before chlorination (Av. 3 yr.)	0.00	38	5	....	290
After chlorination (Av. 4 yr.)	0.20	5	¾	....	225
Yearly difference		33	4¼	....	75

filled bath tubs exhibited 60 000 and 30 000 units respectively. This is one of a class of organisms having a great tendency to float in the upper water.

In January, 1925, chlorination of the Catskill Aqueduct water was started at Ashokan Reservoir. This treatment is purely a sanitary measure using average dosages of only 0.20 p.p.m. of chlorine with only a few hundredths residual. Table 8, covering records for 1922 to 1928, shows that

treatment of the aqueduct water with copper sulphate has been reduced from 38 tons a year to only 5 tons a year since chlorination was begun, a saving of 33 tons yearly. A drop in time of treatment from an average of 5 months yearly to ¾ month is also recorded. The effect has been produced upon the aqueduct water since just as much copper sulphate has been used in the treatment of Kensico Reservoir itself, whether the whole reservoir is considered or only that portion through which the bulk of the water flows. However, there has been also a slight drop in average organisms in the water leaving Kensico Reservoir. The reduction is from 290 to 225 units per cc., or about 25 per cent. As it takes about three weeks for the water to pass through Kensico Reservoir, it is not strange that Kensico itself shows no greater effect since there is every opportunity for separate growths to occur, originating in the reservoir.

One advantage of chlorination is that certain of the organisms not readily controlled by copper sulphate succumb to chlorine. With the development of superchlorination followed by dechlorination with sulphur dioxide, it is likely that the future will see the use of chlorine greatly extended.

Prechlorination and Filtration. Prechlorination with high dosage, 1 p.p.m. or higher, is now employed quite extensively in conjunction with filtration to destroy or to prevent the growth of microscopic organisms in sedimentation and reaction basins and to lessen their interference with filtration. The residual chlorine in the water entering the filters is usually kept down to 0.3 p.p.m. Longer filter runs are obtained in addition to lightening the bacterial load upon the filters. At Council Bluffs,* Iowa, electrolytic chlorine, 0.8 to 1.0 p.p.m., controls algæ in the settling basin. At Davenport,† Iowa, *Melosira* in sufficient numbers to interfere with filtration has been controlled by 2 p.p.m. of chlorine.

Direct Chlorination of Reservoir. Cohen in Texas (1926) and Mangun‡ in Kansas City (1927) have used chlorine to treat small reservoirs. Mangun's method applied to a filtered-water balancing-reservoir was very clever. While the reservoir water was low and the reservoir out of service, a heavy dose of chlorine, 5 to 20 p.p.m., was applied to the incoming water by manipulation of gates so as to circulate the water in the reservoir about once an hour as it filled. The dose was based on the capacity of the full reservoir. A dosage of 1 p.p.m. produced a residual of 0.20 p.p.m. at the periphery and of 0.05 p.p.m. at the center and was very effective with *Synedra* in large amounts (13 000 units). The treatment was employed about three times a week during the summer months with no objectionable after-effects. It has controlled all organisms since it was introduced and saved the cost of covering the reservoir, which had been planned.

Miscellaneous Data. Cyclotella has been destroyed by a dosage of 1 p.p.m. *Crenothrix* is another troublesome organism which is readily con-

*American City, Vol. 40, 1929, p. 103.
†Henderson, *Jour. Am. W. W. A.*, Vol. 9, 1922, p. 622.
‡*Jour. Am. W. W. A.*, Vol. 21, 1929, p. 44.

trolled by chlorine or chloramine in amounts of 0.5 p.p.m. Chlorine to the extent of 0.33 p.p.m. has destroyed or prevented formation of jelly masses or fungus slime in well supplies and mains and has prevented clogging of condensers. Gnats of blood worms have been destroyed by 3[1] p.p.m. of chlorine, but the worms themselves are not readily killed. Experimentally, 15 p.p.m. of chlorine or 15 p.p.m. of copper sulphate have been without effect.

Crustacea. Frequent requests are received for methods of controlling *crustacea*, such as *Cyclops* and *Daphnia*. Baltimore[2] controlled *Daphnia* (red variety) in May, 1929, with 1 p.p.m. of chlorine. New Rochelle[3] employed, in 1927, 2 to 3 p.p.m. of chlorine in water passing from one reservoir to another. The chlorine entered the suction end of a pump. The contact period was about 20 minutes. The organisms (*Cyclops*) were not very active at the end of 20 minutes and were dead soon after.

Excess Caustic Lime. Excess caustic lime has been used in some cases to control organisms. Houston[4] states that it was effective in India in killing *Cyclops*. This is important because in that country *Cyclops* is an intermediate host for embryos of the Guinea-worm, which causes disease in man. Adams[5] states that in the water of the Nile, lime in excess or not quite in excess is very destructive to *Cyclops* and *Daphnia*. He also tried other chemicals on these organisms and mentions chlorine or hypochlorite mixed with ammonium sulphate, *i.e.*, chloramine, as effective in a concentration of 1 p.p.m. Chlorine or hypochlorite alone required using a dosage of 2 p.p.m. The other chemicals tried required a much higher dosage.

Billings[6] states that 5 p.p.m. causticity with excess lime at the Grand Rapids Filter Plant controlled *Nitzchia* and *Melosira* which had been present in such large numbers that filter runs had been reduced to two hours.

Basins have been emptied and the sides heavily whitewashed with lime. This has somewhat delayed plant growth and rendered it more easily detached by a jet of water when cleaned, but has also caused growths to occur at greater depths on account of deeper reflection of light.

Weeds. Frequent requests also come in regarding control of weeds or littoral growths. Chemical control seems doubtful. Caird[7] in 1905 stated that *Potamogeton*, at Middletown, New York, after application of 0.3 p.p.m. copper sulphate, rotted at the roots and came to the surface in one reservoir and acted likewise in another reservoir when treated with 0.44 p.p.m. *Nitella flexilis* has been destroyed in four days by 0.1 p.p.m. of copper sulphate in the Dunfermline Water Works, Scotland, as stated by J. D. Cape.[8]

Cutting weeds or tearing them up by the roots, however, seems to be

[1] A dosage of 1.2 p.p.m. was successful at Elizabeth City, N. C.—*Jour. A. W. W. A.*, Vol. 21, 1929, p. 1604.
[2] Personal communication from Hopkins.
[3] Flentje, Jour. N. E. W. W. A., Vol. 43, 1929, p. 40.
[4] 19th Annual Report, p. 9.
[5] *Water Works Engineering*, Vol. 29, 1927, p. 361.
[6] *Eng. News-Record*, Vol. 98, 1927, p. 875.
[7] *Eng. News*, 1905, p. 33, quoted in U.S. Department of Agriculture, Bureau of Plant Industry, Bull. 76, p. 23.
[8] *Municipal Engineering and Sanitary Record*, Vol. 79, 1927, p. 611.

TABLE 9.— CHEMICALS REQUIRED FOR TREATMENT OF DIFFERENT GENERA.

Organism.	Odor.	Copper Sulphate.		Chlorine.
		p.p.m.	Lb. per m.g.	p.p.m.
Diatomaceæ:				
Asterionella.‡	Aromatic, geranium, fishy.	0.12*–0.20*	1.0– 1.7	0.5*–1.0*
Cyclotella.†‡	Faintly aromatic.	.....	.....	1.0
Diatoma.†	Faintly aromatic.	.....	.....	.....
Fragilaria.†		0.25	2.1	.....
Melosira.†‡°		0.33	2.8	.... 2.0
Meridion.	Aromatic.	.....	.....	.....
Navicula.†		0.07	0.6	.....
Nitzchia.°		0.50	4.2	.....
Synedra.†‡	Earthy.	0.36*–0.50*	3.0–4.2	.... 1.0
Stephanodiscus.		0.33	2.8	.....
Tabellaria.‡	Aromatic, geranium, fishy.	0.12*–0.50*	1.0 – 4.2	0.5*–1.0
Chlorophyceæ:				
Cladophora.†		0.50	4.2	.....
Closterium.		0.17	1.4	.....
Coelastrum.†		0.05 –0.33	0.4– 2.8	.....
Conferva.†		0.25	2.1	.....
Desmidium.		2.00	16.6	.....
Dictyosphaerium.‡	Grassy, nasturtium, fishy.	.....	.....	0.5 –1.0
Draparnaldia.		0.33	2.8	.....
Eudorina.	Faintly fishy.	10.00	83.0	.....
Enteromorpha.		0.50	4.2	.....
Gloeocystis.	Offensive.	.....	.....	.....
Hydrodictyon.	Very offensive.	0.10	0.8	.....
Microspora.		0.40	3.3	.....
Palmella.		2.00	16.6	.....
Pandorina.	Faintly fishy.	10.00	83.0	.....
Raphidium.		1.00	8.3	.....
Scenedesmus.		1.00*	8.3	.....
Spirogyra.†		0.12	1.0	.....
Staurastrum.		1.50	12.5	.....
Tetrastrum.		.....	.....	.... 1.0
Ulothrix.		0.20*	1.7	.....
Volvox.‡	Fishy.	0.25	2.1	0.3*–1.0
Zygnema.		0.50	4.2	.....
Cyanophyceæ:				
Anabaena.‡	Moldy, grassy, vile.	0.12*	1.0	0.5*–1.0
Aphanizomenon.‡	Moldy, grassy, vile.	0.12*–0.50*	1.0– 4.2	0.5*–1.0*
Clathrocystis.	Sweet grassy, vile.	0.12*–0.25*	1.0– 2.1	0.5*–1.0
Coelosphaerium.‡	Sweet grassy.	0.20*–0.33	1.7– 2.8	0.5*–1.0
Cylindrospermum.	Grassy.	0.12	1.0	.....
Microcystis.		0.20	1.7	.....
Oscillaria.†		0.20 –0.50*	1.7– 4.2	.....
Rivularia.	Moldy, grassy.	.....	.....	.....
Protozoa:				
Bursaria.	Irish moss, salt marsh, fishy	.....	.....	.....
Ceratium.†‡	Vile (rusty brown color).	0.33	2.8	0.3*–1.0
Chlamydomonas.		0.50	4.2	.....
Cryptomonas.	Candied violets.	0.50	4.2	.....
Dinobryon.‡	Aromatic, violets, fishy.	0.18*	1.5	0.3*–1.0
Euglena.		0.50	4.2	.....
Glenodinium.	Fishy.	0.50*	4.2	.....
Mallomonas.	Aromatic, violets, fishy.	0.50	4.2	.....
Peridinium.	Fishy, like clam-shells.	0.50*–2.00	4.2–16.6	.....
Synura.‡	Cucumber, muskmelon, fishy, bitter.	0.12*–0.25*	1.0– 2.1	0.3*–1.0
Uroglena.‡	Fishy, oily, cod liver oil.	0.05*–0.20*	0.4– 1.6	0.3*–1.0

TABLE 9.—CHEMICALS REQUIRED FOR TREATMENT OF DIFFERENT GENERA.—*Continued.*

Organism.	Odor.	Copper Sulphate.		Chlorine. p.p.m.
		p.p.m.	Lb. per m.g.	
Crustacea:				
Cyclops.††°		.....	.....	1.0 –3.0
Daphnia.††°		2.00	16.6	1.0 –3.0
Schizomycetes:				
Beggiatoa.†	Very offensive decayed.	5.00	41.5	.....
Cladothrix.‡	Mould-like.	0.20	1.7	.....
Crenothrix.†‡	Very offensive decayed, medicinal with chlorine.	0.33 –0.5*	2.8– 4.2	0.5* ...
Leptothrix.†		.....	.....	.....
Sphaerotilus natans.	Very offensive decayed.	0.40	3.3	.....
Thiothrix.†‡	Very offensive decayed.	.....	.....	0.5*–1.0
Fungus:				
Leptomitus.		0.40	3.3	.....
Saprolegnia.†		0.18	1.5	.....
Miscellaneous:				
Chara.†		0.10 –0.50	0.8– 4.2	.....
Nitella flexilis.†	Objectionable.	0.10	0.8	.....
Potamogeton.†		0.30 –0.80	2.5– 6.7	.....

Note: The organisms for which odors are recorded have been encountered in sufficient numbers at one time or another to cause the characteristic odor.

the most practical way of controlling them. A flexible saw is used between two boats or a cable with clips and swivels. Such equipment has been used in hot countries and also by Domogalla§ at Madison, Wis.

Table 9 presents data brought up to date on dosages of copper sulphate, and dosages of chlorine required for the destruction of microscopic organisms, including also odors and tastes produced. It is based on data published by Moore and Kellerman, and by Whipple, as well as upon various other sources and personal experience.

DISCUSSION.

HAROLD E. WATSON.* In the use of copper sulphate for algæ control at Newport two problems have presented themselves: (1) getting a reasonably good distribution of the copper salt throughout the entire body of water, and (2) obtaining a sufficient concentration in those portions of the reservoir which are rather inaccessible due either to shallowness or the growth of rushes. Two general methods of application have been used; one employing the crystallized copper sulphate, and the other dehydrated

*Dosage successful in New York City's supplies.
†These organisms have caused trouble other than odor.
‡These organisms have been affected by chlorine producing characteristic odor and in many cases controlled by dosage ranging from 0.3 to 3 p.p.m. depending largely on amount of organisms.
°Controlled by excess caustic lime; 5 p.p.m. in the case of the diatoms.
§*Eng. News-Record*, Vol. 97, 1926, p. 950.
*Newport Water Co., Newport, R. I.

copper sulphate, or "copper dust" such as is used in agricultural dusting mixtures.

It has been found that in towing bags of the crystals behind a motorized boat that the rate of solution varies greatly. A fresh bag with considerable fine and soft sulphate dissolves rapidly until there is left a collection of the larger and harder crystals which dissolve much more slowly. To avoid this condition there has been used instead of bags, a long, narrow box. This is about 5 in. square and 3 ft. long, closed at one end and open at the other. Two of the long sides of this box are of copper screening, and the rest of wood. The box is attached by hinges at the open end to a short plank laid across the boat. The entire outfit then resembles an outrigger, with the closed end of the box swinging down below the surface of the water. When the boat is in motion water passes readily through the copper screen sides of the box, and if an obstruction is met the hinges permit the low end to ride up and over without difficulty. The crystallized copper sulphate is fed into the upper open end by hand shovels from a stock carried in the boat. In this way it is easy to keep the copper in the box at a constant level and to vary the rate of solution by varying that level. The treatment can thus be carried on continuously. This method has been found to give an even distribution, and is easy of manipulation in the open water of the reservoir.

For treating the more inaccessible portions of the reservoir, and the areas where rushes interfere badly, a saturated solution of copper sulphate, sprayed by hose from a motor-driven pump has been successfully used. Small hand force-pumps are much less cumbersome, and equally good for these small areas.

Experiments with dehydrated copper sulphate or "copper dust" both for treating the entire reservoir and for reaching the more difficult sections have been made. Copper sulphate in this form is very quickly soluble, and of course, being more concentrated, less bulk is required. The amount used was theoretically equivalent in copper content to the required dose of crystallized sulphate. It was applied by manually-operated agricultural blowers. One great difficulty encountered was the persistent tendency for the fine dust to blow back into the boat and into the eyes of the operators, in spite of the most strenuous efforts to keep on the windward side. On this account, experiments with a power blower were not attempted. In the open reservoir the distribution seemed no better than that obtained with the crystals, but the solution seemed to be effected nearer the surface of the water. Later, experiments were made using a water ejector to handle the dust. The ejector, with attached hopper, was mounted near the bow of the boat. Pressure was obtained from a small motor-driven pump also mounted in the boat. This outfit handled the dust successfully, and the output from the ejector was sprayed a distance of about 25 ft. With no other method tried here has it been possible to secure as concentrated a dose in rush-infested areas. The greater cost of the dehydrated copper sulphate and the necessity for rather cumbersome apparatus for handling have deterred further experimentation.

GEORGE G. BOGREN.* In connection with the subject of algæ control, it may be of interest to recount the experiences with two bodies of water in greater Boston, namely, Spy Pond in Arlington and Lake Quannapowitt in Wakefield. Neither of these bodies of water is used as a source of water supply. Both have thickly populated catchment areas. Both are centrally located in their community, and are bordered in part by high-class residences. Lake Quannapowitt is much used for bathing, and is surrounded by a boulevard and a municipal park of scenic beauty. The capacity of each is about 550 m.g., while the area of Spy Pond is 115 acres and that of Lake Quannapowitt 230 acres. Spy Pond is 34 ft. deep at its deepest point, and undergoes seasonal overturns and stagnation typical of deep ponds (Figures 5 and 6). Lake Quannapowitt, on the other hand, has a maximum depth of 12 ft. and is in constant vertical circulation due to high wave action.

Conditions Prior to Control. In both waters, *Coelosphaerium* grew profusely prior to control (see Figure 7). The colonies of these organisms agglomerated in balls up to ½ in. in diameter and floated in thick patches when the water was calm, to be washed up on the shore when wind and waves arose, there to decay and give off obnoxious odors.

Control with Copper Sulphate. About ten years ago the water in Spy Pond was treated with copper sulphate in the late fall to improve the quality of ice harvested. This treatment has been continued ever since, the dose averaging 0.35 p.p.m. and the treatment being successful.

In 1927, the municipalities in which these lakes are situated decided to control the growth of algæ in the summer months. Accordingly, regular inspections and microscopical examinations were made, and when the algæ increased to numbers that threatened to become objectionable, copper sulphate was applied. This routine procedure has been continued in 1928 and 1929.

Obviously the standard of quality in these cases is based on a different criterion from that of sources of water supply. Appearance is the deciding factor, the microscopical examination serving to show invisible changes in numbers or genera. The type of organism is important, since for example, 2 000 or 3 000 standard units per cc. of *Coelosphaerium* might be offensive, while double that quantity of *Pediastrum* would be scarcely noticeable. The average dose of chemical at Spy Pond has been 0.35 p.p.m., while at Lake Quannapowitt it has been 0.42 p.p.m. These doses remove practically all the organisms.

Method of Application. In both these places the copper sulphate is applied by dragging through the water burlap bags filled with the chemical, four bags being suspended from a frame on each boat, the latter being either rowed by hand or towed by a motor boat. Copper sulphate is added to the bags in small portions with a long-handled shovel (see Figure 8).

Results of Treatment (see Figure 7). The two bodies of water reacted differently to the copper sulphate treatment.

*With Weston and Sampson, Consulting Engineers, Boston, Mass.

In Spy Pond, one treatment in July, 1927 sufficed to maintain the water of good appearance until November of that year, while in 1928 and 1929 two treatments were necessary, the average period between summer treatments being 9 weeks. The organisms do not reappear until some time after

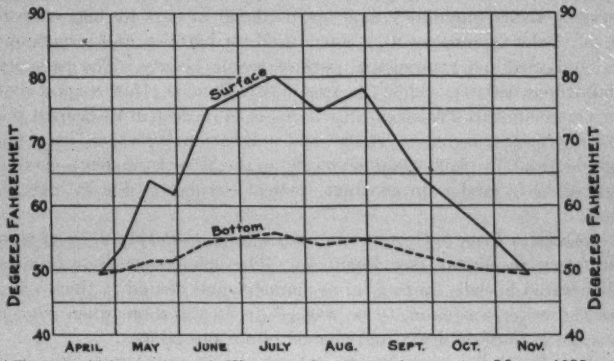


FIG. 5.— TEMPERATURE OF WATER IN SPY POND, ARLINGTON, MASS., 1928.

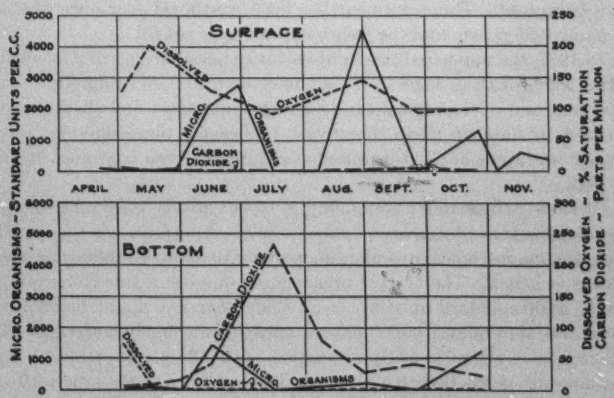


FIG. 6.— DISSOLVED GASES AND MICROSCOPIC ORGANISMS IN SPY POND, ARLINGTON, MASS., 1928.

treatment and increase at an even rate. The water remains free from any organisms visible to the naked eye for seven or eight weeks when suddenly the organisms multiply profusely. It is interesting, however, that while *Coelosphaerium* was the predominant organism during the past ten years of late-fall treatments and continued to hold practically exclusive sway during

the summer seasons of 1927, 1928 and 1929, the predominant organisms at the time of late-fall treatment (late November) during the last three years were *Pediastrum, Synura,* and *Coelastrum,* respectively.

In the case of Lake Quannapowitt, three treatments were necessary in

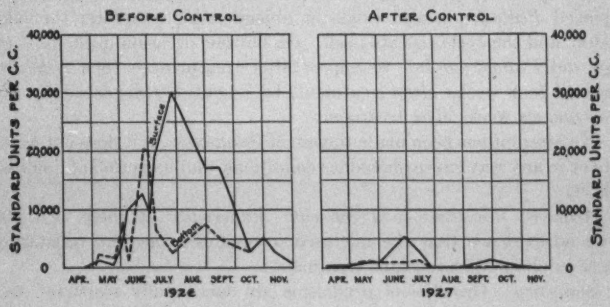


FIG. 7.— MICROSCOPIC ORGANISMS IN SPY POND, ARLINGTON, MASS., BEFORE AND AFTER CONTROL WITH COPPER SULPHATE.

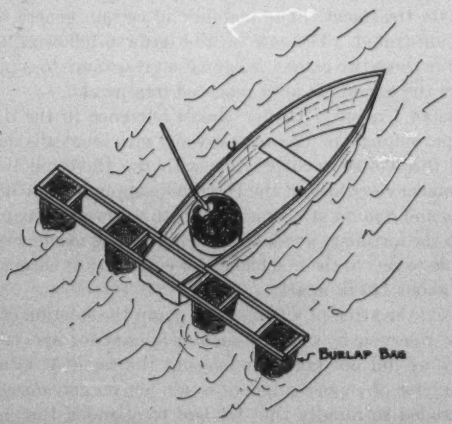


FIG. 8.— RIGGING FOR APPLYING COPPER SULPHATE CRYSTALS FROM A BOAT.

1927, two in 1928, and three in 1929. The average period between treatments was 5 weeks. Organisms thrive much better here than in Spy Pond, in spite of the higher turbidity of the water. Here, however, the incompatibility of species is strikingly demonstrated. The following cycle of events is typical of the three years since control was begun:

From April to July, organisms of miscellaneous genera increase to

3 000 or 4 000 standard units per cc.; the lake is then treated; within a week *Pediastrum*, which is present in negligible amounts before treatment, predominates in concentrations ranging from 2 000 to 12 000 standard units per cc.; 3 weeks after treatment, *Coelosphaerium* and *Pediastrum* are present in equal quantities; 5 weeks after treatment, *Coelosphaerium* has entirely displaced *Pediastrum*, and exists in objectionable amounts; the lake is treated, and the cycle repeats itself. On but one occasion in the past three years did *Pediastrum* fail to appear after treatment — then *Asterionella* appeared four weeks after treatment, to be entirely displaced by *Coelosphaerium* six weeks after treatment.

No attempt has been made to control *Pediastrum* as it does not agglomerate or in any way cause obnoxious conditions, and its period of dominance is short.

Acquired Resistance to Treatment. Experience at these two places shows no evidence that the microscopic organisms acquire resistance to copper sulphate after repeated treatments.

Summary. Growths of organisms are successfully restricted to inoffensive numbers in both waters. Certain genera of organisms may exist in very large numbers and be scarcely noticeable, and not at all objectionable to sight. The predominance of one genus is temporarily upset by copper sulphate treatment. The inability of certain genera to thrive together is demonstrated. The rate of after-growth following treatment is very different in these two cases. No apparent resistance to copper sulphate is acquired by the organisms after repeated treatments.

E. Sherman Chase*. Doctor Hale's reference to the difficulties of applying copper sulphate to reservoirs covered with ice recalls the experience we have had this winter in coöperation with the Haverhill Water Board. Two of the smaller reservoirs of the Haverhill supply became heavily laden with *Uroglena* and *Synura* at a time when both reservoirs were covered with ice. Through the fortunate availability of ice-cutting machinery the Water Board was able to secure the machinery for cutting slots through the ice in parallel lines about 150 ft. apart.

In one pond the attempt was made to pump the solution of copper sulphate into the reservoir by a device such as is used for spraying gardens. Unfortunately we did not take into account the rapidity with which the corrosive character of copper sulphate would act on galvanized iron cans. The cans corroded so rapidly that we had to abandon that method and apply the solution by dragging burlap bags filled with the copper sulphate in the water through the slots. This method was effective and the number of organisms was reduced from several thousand per cubic centimeter to practically none in about a week's time.

In the second reservoir the solution-feed method was more successful. In that case a barrel was mounted on a sled, and from the barrel the copper sulphate solution passed through a flexible hose into a horizontal pipe with

*Of Metcalf and Eddy, Consulting Engineers, Boston, Mass.

perforations about one-eighth of an inch in diameter at 6-in. intervals. This horizontal pipe was 10 to 12 ft. long, and was carried through the water at right angles to the line of the slot. In that particular pond the prevalent organism was *Uroglena*, about 100 000 per cubic centimeter. In approximately ten days these organisms were practically destroyed.

FIG. 1.—AERIAL PHOTOGRAPH OF RAYMOND DAM.

July, 1925, looking north. Concrete core-wall nearly completed. Reservoir basin to the left of the dam. Location of overflow weir is in lower left corner.

THE WANAQUE WATER-WORKS PROJECT.

BY ARTHUR H. PRATT.*

[*Read September 25, 1930.*]

The Wanaque Water-Works Project is a district water supply built for the use of a group of municipalities in the North Metropolitan Area of New Jersey. The source of supply is the Wanaque River, one of the upper tributaries of the Passaic River which is the largest stream in the northeastern part of the state.

The run-off from an area of 94.4 sq. miles is impounded in the Wanaque Reservoir having a storage of 29 600 million gal., and the yield of 100 m.g.d. is conducted to the cities through an aqueduct 20 miles long, consisting mainly of a 74-in. twin steel pipe-line.

The construction work on this project was begun in 1920 and was sufficiently completed last spring (1930) to deliver water at the end of the aqueduct. The cost of the completed project will approximate $27 000 000.

The North Metropolitan District of New Jersey.

The area of New Jersey which is in part supplied with water by these works is an important section of the great metropolitan area of New York, one of the largest concentrations of population in the world.

The New Jersey portion of the metropolitan area, as defined by the Committee on Regional Plan of New York and its Environs, is about 2 200 sq. miles in area. It contains the large cities of Newark, Jersey City, Paterson, Bayonne and Elizabeth and 260 other municipalities. While for governmental purposes it is divided into many municipal units, its problems, so far as the major utilities are concerned, are practically identical.

The population of the North Jersey Metropolitan District, as it is called — although the name has no legal significance — was about 2 million in 1920. The 1930 census shows the population of the six counties of Essex, Hudson, Passaic, Bergen, Union and Middlesex to be 2 698 000.

Huge engineering works have been built for the purpose of improving means of transportation in this area and to link it with the New York portion of the metropolitan district including the Holland Tunnel and superhighway connections and three bridges to Staten Island. The Fort Lee Bridge is under construction, additional Hudson River tunnels are in the study stage, and the new Pennsylvania terminal is being built in Newark. The State Highway Department and various municipal units are coöperating in a very extensive main highway development.

All these improvements in connection with the many natural advantages of this area, such as large meadow areas available for industrial

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development, port facilities in the vicinity of Newark Bay and attractive suburban areas for residential purposes, destine the North Jersey Metropolitan District for great future growth. Future population estimates are 4 million for 1950 and 5 million for 1960.

Water Supply for the District.

Water is supplied to this district from many sources grouped into some 40 separate systems, about half of which are municipally owned; the remainder are private water companies. The larger municipal supplies are the Pequannock system of Newark and the Boonton works of Jersey City, both of which store upland surface waters from tributaries of the Passaic.

The principal private water companies are the Hackensack Water Company, supplying a filtered, stored surface supply from the Hackensack River to about 50 communities in and adjacent to Bergen County; the Passaic Consolidated Water Company, supplying filtered Passaic River water to 10 communities in and adjacent to Passaic County, and the Elizabethtown and Plainfield-Union Water Companies, purveying a ground water and filtered surface supply to communities in Union County.

There are many well supplies, both municipally- and corporation-owned. The average consumption for the District from all listed sources in 1929 was about 310 m.g.d. Most of these water works have been described in papers before this Association on account of their interest and importance in their day. A list of the engineers engaged on these projects, either in a major or minor capacity, would almost make a complete roster of the water-works profession in the United States. Among the members of the New England Water Works Association who should be particularly mentioned are:

The late J. James R. Croes, Allen Hazen, Rudolph Hering and Clemens Herschel, Honorary Members; the late W. B. Fuller, Emil Kuichling and Reuben Sherreffs, Members; Harrison P. Eddy, John R. Freeman and J. Waldo Smith, Honorary Members; John H. Cook, Allen W. Cuddeback, D. W. French, George W. Fuller, John H. Gregory, Nicholas S. Hill, Jr., George A. Johnson, Morris Knowles and Thaddeus Merriman, Members; and George G. Honness, Dabney H. Maury and Walter H. Sears, former members.

An examination of the topography of New Jersey makes it evident to anyone that the streams which flow from the northeastern highlands of the state are the ideal sources of water supply for the various cities in the northerly part of the state. This was appreciated many years ago, and the capitalist was by no means slow to grasp the idea in all its possibilities. For about a century there were two dominant interests in the watershed of the Passaic River, the Society for the Establishing of Useful Manufactures and the Morris Canal and Banking Company. The former, founded by Alexander Hamilton, was incorporated in 1791 and claimed the right to the undiminished flow of the Passaic River above Great Falls, the run-off from

about 785 sq. miles. The Canal Company was chartered in 1824 and claimed the rights to sufficient water to maintain navigation, the water being principally drawn from Greenwood Lake and Lake Hopatcong. The canal was taken over by the state of New Jersey on March 1, 1923.

Without the coöperation of these companies, the success of any sizable scheme to supply water from the Passaic Watershed above Little Falls would have been impossible in the early days. This coöperation was secured, and the water power interests, representing large financial resources, combined in plans for providing a water supply for the various municipalities adjacent to the Passaic Valley. The plan for the furnishing of water to the municipalities from this source had its beginning in 1881, at which time Jersey City, Newark, and some of the smaller communities were using water of doubtful quality from the lower reaches of the Passaic River.

About this time the need for more water in New York City, which finally resulted in the construction of the New Croton Aqueduct, was productive of many plans to supply the city from other sources, among which the highland tributaries of the Passaic were looked upon with favor, especially the Ramapo. The greater part of this watershed lies in New York State, and in 1883 legislation was enacted which made it possible for a corporation to divert to New York City 50 m.g.d. of the water from the Ramapo before it entered New Jersey. Objections to such diversion were raised, and nothing ever came of the scheme.

In 1887 and 1888, the project to furnish Passaic River water to New York City was revived, but this time it was proposed to pump from the river at Little Falls through a conduit passing beneath the Hudson River. The project was elaborately presented, and a large sum of money was spent in trying to tunnel under the Hudson River, but it came to naught. Upon the failure to sell their water to New York, the water interests turned to cities in New Jersey.

During the years between 1880 and 1902 various private water companies were active in water proposals which culminated in the sale of water to Montclair, construction and sale of the Pequannock and Boonton works to Newark and Jersey City respectively, and construction of the purification plant at Little Falls.

The Hackensack Water Company is older, having its beginning in 1869 and being enlarged step by step, until it now supplies almost all the communities in its vicinity. The Elizabethtown Water Company is still older.

State Commissions. The disadvantages of these various arrangements with different private water companies were early recognized, and the creation of a state administrative agency for water matters was undertaken. The First State Water Supply Commission reported upon a joint system in 1884, but no action was taken, and finally the Commission lapsed. In 1907 another State Water Supply Commission was established having general jurisdiction over water-supply matters. Application was made to

this Commission by the city of Newark, looking forward to future provision for her growing water needs, to develop a supplementary supply on the Wanaque River. This was opposed by other municipalities and was denied by the Commission, but it undertook to arrange for a joint supply and in 1911 received such an application from a group of eight municipalities.

At the time, a number of these communities were being supplied by the East Jersey Water Company, and it was decided to make an appraisal of the company's distribution system and supply works at Little Falls before undertaking the construction of new works. In 1913 a board of engineers (Clemens Herschel, Nicholas S. Hill, Jr., and Dabney Maury) returned an appraisal and the Commission negotiated for the purchase of the properties on behalf of the cities. The following year the Commission reported upon the Wanaque project, recommending a 50-m.g.d. development at a cost of $5 000 000. The courts, however, decided that the Commission could not issue bonds without affirmative vote of the people of the state. A referendum, held in 1915, was lost by a close vote, and the Commission passed out of existence.

North Jersey District Water Supply Commission.

The North Jersey District Water Supply Commission was created in 1916 with powers designed to permit the construction of district works, even though the constitution of the state of New Jersey forbids the issuance of state bonds for such purposes except by state-wide referendum.

The Commission is authorized to contract with one or more municipalities to design, build and operate water works. The municipalities borrow the money in the usual way and pay it over to the Commission in accordance with the terms of the contract. This method provides for financing all branches of the work from the preliminary studies to operation, but puts the Commission in the position of an agent or trustee for others rather than an independent state agency. The law works, however, and the Wanaque project has been built by that method. Other constructive steps have also been accomplished.

After prolonged negotiation, and some litigation, it developed that no municipality was ready at the time to actually contract for the construction of the Wanaque project except Newark. That city accordingly signed a contract with the Commission on October 31, 1918, providing for:

(1) The construction of a large reservoir on the Wanaque River at El. 275, described in detail;
(2) A line of pipe, mainly 72 in. in diameter, to deliver 50 m.g.d.;
(3) The cost to be $9 047 250;
(4) Any other municipality may become a party to the contract, under certain conditions, one of which is the refund of the proportional part of funds, with interest, expended on behalf of the original contracting municipality.

This contract was executed on behalf of the city of Newark by the late Mayor Thomas L. Raymond. The vision and wisdom which led him to consent to the conditions of this unique instrument are universally testified to by all who are conversant with the circumstances. His great public spirit in the matter has been recognized by naming the principal structure of the project "Raymond Dam." Thus after many years of delay and much negotiation, actual construction of the Wanaque project was begun.

The other interested municipalities continued to consider participation in the project. By 1922 the entry of Paterson, Passaic and Clifton was practically assured. In the following year actual applications had been received from seven additional municipalities, and several others indicated probable participation. Meanwhile actual construction had reached a stage which demanded immediate decision if the project were to be enlarged. The City of Newark again stepped into the breach and executed a supplementary contract authorizing an enlarged project to the extent of $18 000 000 and providing more definitely for the subsequent entry of other municipalities. It was not until 1925 that it was assured just what cities would actually participate in the Wanaque project. The final participants and allotments are as follows:

Newark	40.5 m.g.d.	Clifton	6.75 m.g.d.
Paterson	20 m.g.d.	Montclair	5 m.g.d.
Kearny	12 m.g.d.	Bloomfield	4 m.g.d.
Passaic	11 m.g.d.	Glen Ridge	0.75 m.g.d.
	Total		100 m.g.d.

The project was enlarged to 100-m.g.d. capacity, reservoir-elevation 300 (25 ft. higher than first designed) and main aqueduct capacity of 150 m.g.d. The estimated cost was $20 350 000.

It should be noted that the law places responsibilities upon the Commission which have resulted in the undertaking of a considerable amount of work in addition to the construction of the Wanaque project. No municipality may undertake water works in a new watershed without permission of the District Commission. This involves the Commission in an investigation and consideration of many applications and in a measure tends to prevent the construction of conflicting projects. The Commission is also empowered to take over private water companies and while this authority has never been exercised, a number of appraisals of existing plants have been made, and studies leading to proper coördination of existing and new supplies have been undertaken.

Wanaque Reservoir Design.

The Wanaque River rises in Greenwood Lake, a narrow body of water, about 6 miles long, lying on the boundary line of the states of New Jersey and New York. This lake was originally formed by the construction of a dam to store water for feeding the old Morris Canal. The river flows south

until it is joined by the Pequannock and the Ramapo. Together, they are called the Pompton River which continues south until it meets the main Passaic about two miles above Little Falls.

The watershed tributary to Wanaque Reservoir is mountainous, having a maximum elevation of 1 487 and an average of 760. It is generally wooded and sparsely inhabited. The rock formation is gneiss, which outcrops on the hills. The valley bottom in which the reservoir is located has an extensive deposit of sand and gravel. The catchment area originally tributary to the Wanaque River is 90.4 sq. miles, of which 27 sq. miles are tributary to Greenwood Lake. About 4 sq. miles of Post Brook, an adjacent watershed, have been diverted into the reservoir, making the total drainage area 94.4 sq. miles.

The first Newark contract, based on the design recommended by the former State Water Supply Commission, Morris R. Sherrerd, Engineer, provided a reservoir with a storage of 12 000 million gal. The development was estimated to yield 50 m.g.d., and the construction of the Raymond Dam and acquisition of real estate were continued on that basis for several years. It became evident, however, that the future needs of the district would not be met by a project of this size, even though the names and location of the municipalities that would ultimately participate were not known. Plans and estimates for presentation to Newark and other municipalities were made for a number of larger developments, but it was finally decided to develop the project to its fullest possible extent. Application was accordingly made by the Commission to the State Department of Conservation and Development. That department, under date of January 16, 1924, granted approval for diverting the waters of the Wanaque River and Post Brook "to the maximum amount economically obtainable," subject to a number of conditions, one of which was:

> That at all times the flow of the Wanaque River below the dam shall be maintained at an amount not less than seven million (7 000 000) gallons per day plus such quantity of water up to three million (3 000 000) gallons per day as is discharged during the same period from Greenwood Lake. If a quantity in excess of three million (3 000 000) gallons per day is discharged from storage in Greenwood Lake for use other than the use of the North Jersey District Water Supply Commission, an amount equal to such draft from Greenwood Lake shall be discharged from the Wanaque Reservoir, and in addition thereto such amount as shall be required to make the total discharge from the reservoir at least ten million (10 000 000) gallons per day.
>
> That the applicant shall permit to flow down Post Brook below the point of diversion at all times three hundred fifty thousand (350 000) gallons of water per day, provided the natural flow of said Post Brook shall equal that amount; and if the natural flow is less than three hundred fifty thousand (350 000) gallons, it shall allow the entire flow of the stream to pass the point of diversion.

Yield. Gagings of the Wanaque River were incomplete, but such as were available were slightly in excess of the measured flow of the Pequannock, the next stream to the westward, which had been gaged since 1892 by the city of Newark. The characteristics of the watersheds are very

similar. Accordingly the yield was figured on the basis of the Pequannock run-off, using the driest period, April, 1899, to May, 1902.

The total storage capacity of the reservoir and yields were computed as follows:

Elevation.	Storage million gal.	Yield. m.g.d.
290	20 600	90
300	27 600	108
305	32 100	114

The minimum cost per m.g.d. was computed at flow-line elevation 298. In view of all the conditions, however, a spillway elevation of 300.3, with provision for 2 ft. of flashboards, was adopted, giving a net yield of 100 m.g.d.

The Wanaque Reservoir is about 6 miles long, has an area of 2 300 acres and an average depth of 36.7 ft.

Quality of Water. Swampy areas within the reservoir are small. The steep hillsides, the insoluble character of the rock and the good quality of the overlying soil are all factors tending to produce a water that is soft, low in color and contains only a small amount of vegetable matter in solution. The greatest concentration of population in the watershed, with its potential pollution, is located on the upper reaches of the watershed, a long distance from the reservoir. A great proportion is transient during the summer season and is concentrated in relatively small areas. A few small artificial lakes, real estate developments, have been built in the watershed, but the long periods of storage in Wanaque Reservoir and Greenwood Lake which intervene between this population and the participating municipalities constitute a purifying agency which assures the ultimate consumers of receiving a water of excellent quality.

Aëration is being provided for the elimination of tastes and odors.

In 1922 the firm of Weston and Sampson, reporting upon the quality of Wanaque water, predicted an average color of about 12 p.p.m. and less microörganisms than in the Pequannock supply. They reported that it was not necessary to consider filtration at that time.

The reservoir has now been filled for two years, and the quality of the water has fulfilled all expectations. A recent analysis is shown in Table 1.

TABLE 1.— TYPICAL ANALYSIS OF WANAQUE RESERVOIR WATER AT SURFACE NEAR THE INTAKE.

(Unless otherwise stated results are reported in p.p.m.)

Odor	Cold	2ev	Hardness	20
	Hot	3v	pH Value	7.2
Turbidity		3	Iron	.03
Color		12	Total Solids	32.0
Oxygen Consumed		3.4	Bacteria per cc. — 37.5°C. Agar	8
Nitrogen as	Free Ammonia	.002	Acid colonies per cc. — E.M.B. Agar	0
	Albuminoid Ammonia	.172		
	Nitrites	.000	Presumptive Test for *B. Coli* in 5 10-cc. portions	0
	Nitrates	.06		
Chlorides		2.7	Microörganisms per cc.	193
Alkalinity		14	Amorphous matter per cc.	240

Raymond Dam. Studies of the site of Raymond Dam, made in connection with the first project, resulted in the adoption of the earth type with a core-wall to bedrock about 100 ft. below the surface of the ground at the deepest place. The method adopted for excavating to this great depth was by means of a steel-sheeted trench. In order to permit subsequent raising of the dam to a higher elevation, the core-wall in the first project was designed to be placed downstream from the center. The main embankment was built of sand and gravel, excavated from the bed of the reservoir. A zone of selected embankment material was placed next to the core-wall on the upstream side. The only fine material available for this purpose was top-soil and a layer of fine sub-soil on the flat areas in the vicinity of the dam.

For the original 50-m.g.d. project, the overflow weir and outlet control-works were located at the south end of the dam where rock was close to the surface. For flood control, the river which was naturally located at this end of the dam would be controlled through and over the concrete structures at this end, permitting the earthworks to proceed safely at elevations above possible flood level.

When the project was enlarged, the construction of a weir of this type became unduly expensive on account of its height. Fortunately, bedrock was located near the surface at an appropriate elevation, in a gap in the natural reservoir-wall south of the southerly abutment of the dam. Here, the construction of a low overflow weir would conduct flood waters around the dam. Some excavation of rock was necessary to provide an ample channel of approach, and some rock excavation and training walls were required to retain the floods in the overflow channel until well beyond the toe of the dam. Just below the overflow weir, the rock falls away abruptly forming a deep "pot-hole," then the rock rises and forms a barrier or reef at an elevation some 20 ft. below the weir. The pot-hole was filled with sand and muck, originally constituting a swamp hole which never dried out. About 40 000 cu. yd. of earth were excavated from this hole so that its washout into the channel by future floods was prevented. The hole was permitted to fill with water, and a deep, natural, stilling-pool is thus provided just below the spillway. From this pool, the water again drops over the natural rock barrier into the overflow channel. The overflow works were designed for a flood of 18 000 sec.-ft.

The works for flood control during construction required redesign for the larger dam and finally consisted of a double-barreled, 14-ft. concrete conduit through the whole width of the dam. This conduit passes through the substructure of the upper gatechamber and, upon the completion of the dam, is used in connection with the outlet works. One conduit is used to draw water from the bottom of the reservoir; the other is closed at the upstream end, but is provided with a chimney having ports at the top, thus providing facilities for drawing water from the mid-depth elevation. Openings in the gatechamber wall at the top of the reservoir provide a surface-elevation intake. The double conduit provided ample capacity for all floods

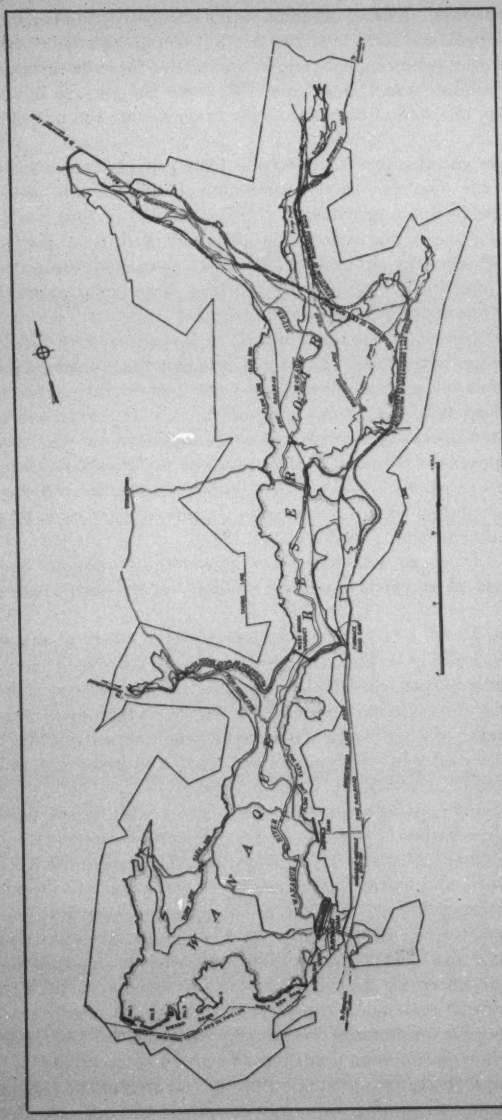

FIG. 2.— PLAN OF WANAQUE RESERVOIR.
Showing the location of all important structures, the existing and relocating highways and railroad.

during construction. During different stages of construction the river flow was switched back and forth from one conduit to the other, as convenience required, but always leaving both conduits available for extreme flood flows. The unused conduit was a great convenience for the passage of men and materials from one side of the dam to the other during the period of construction.

The upper gatechamber, 43 x 56 ft. in plan, provides two independent outlets from the reservoir to the aqueduct. Four 6 x 4-ft. electrically-operated sluice gates are provided in addition to a 24-in. gate valve to let water down the river. The outlet works also provide the usual screens, stop planks and shutters for controlling the outlet elevation. Stop disks are provided for insertion into grooves on the back-water side, in case the removal of any one of the gates should be required.

The gate-operating room is at the top of the chamber with its roof on a level with the top of the dam. This room, which is slightly larger than the lower portion of the gatechamber, houses the gate-operating machinery, stop planks, stop disks and screens when not in use. It also provides space for cleaning and operating screens and upper intake racks. An overhead trolley-rail equipped with electric hoist provides facilities for moving and operating the equipment. Provision for both electric and hand operation of all machinery is provided. Entrance to the operating room is by means of a stairway on the face of the dam.

From the upper gatechamber, water is conveyed through two 72-in. steel pipes, laid in the stream-control conduit, to the headworks of the aqueduct.

Secondary Dams. At the southerly end of the reservoir are several points where the divide is below the elevation of the flow-line, thus making necessary smaller dams to close these gaps. For the first project, at El. 275, these were short and quite unimportant, but for the final project these dams have a total length of 6 100 ft. and a maximum height of nearly 42 ft. These dimensions were such as to warrant careful study and investigation of the location and type to be adopted.

At a location about 1½ miles west of Raymond Dam, at the southwest corner of the reservoir, is a group of four structures designated Green Swamp Dams Nos. 1, 2, 3 and 4. At the site of No. 1, bedrock was 40 ft. below the surface, and borrow pits were available nearby. The earth type with concrete core-wall was, therefore, adopted having a section somewhat lighter than that for Raymond Dam. No. 3 is a minor structure of similar type. For Nos. 2 and 4, where rock was near the surface and embankment-material difficult of access, masonry structures were built. The section is of the gravity type and was designed to withstand the maximum static water pressure, plus an assumed ice pressure of 20 000 lb. per linear foot exerted at the flow-line, and an uplift due to water pressure under the dam, or in a horizontal joint, acting on one-third of the area of the base at the upstream edge and decreasing uniformly to zero at the toe. Special pre-

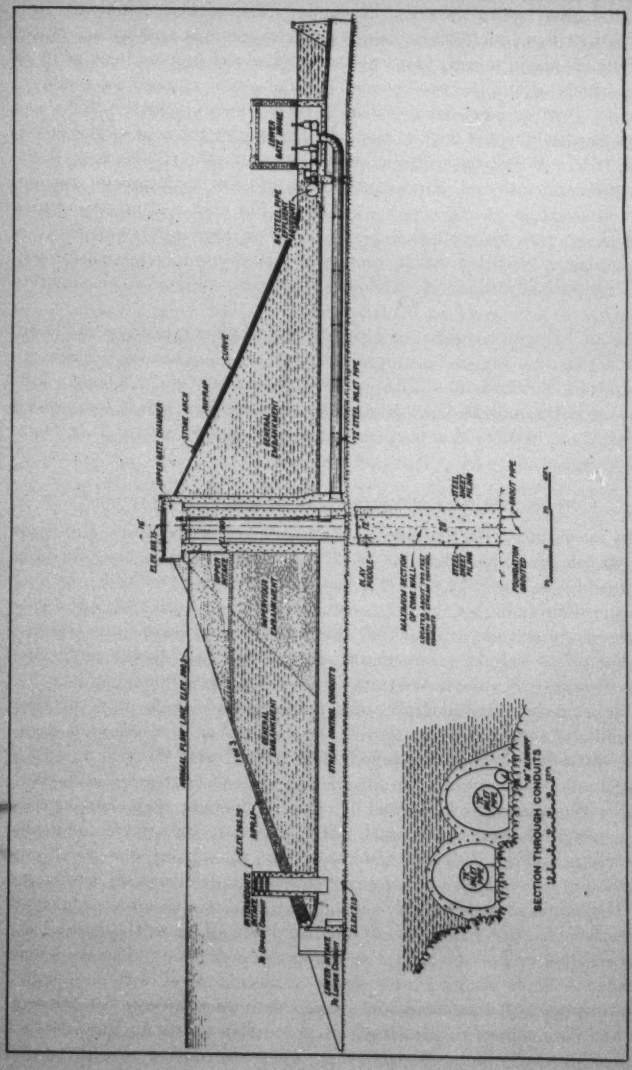

FIG. 3.— RAYMOND DAM.
Cross-section through outlet works.

cautions were taken to minimize and control leakage through both the horizontal and vertical construction-joints. The vertical joints are provided with tongue-and-groove joints between sections and with a water cut-off near the upstream face consisting of a continuous, bent strip of copper which bridges the gap between sections and is securely anchored on each side. Any leakage passing this cut-off system is picked up by a well at each joint connected with a drain discharging at the foot of the downstream face. A horizontal drain, consisting of a split tile leading to the wells, was built into each horizontal joint to still further intercept seepage. These dams are in an inaccessible location. For that reason, no attempt was made to give the surface a special finish or decorative treatment. A plain coping is provided; also a footway on the top of the structure protected by simple railings of galvanized-iron pipe supported on concrete posts.

About halfway between the Green Swamp Dams and Raymond Dam, an earth concrete-core-wall structure, 2 200 ft. long and having a maximum height of 42 ft., was built. This is called Wolf Den Dam. About a mile northwest of Raymond Dam is another similar structure, 900 ft. long, called Midvale Dam. Still farther north is a small dike called Furnace Road Dam.

Construction of Raymond Dam and Appurtenances.

In accordance with the original Wanaque-Newark contract, Raymond Dam was designed complete for El. 275 and advertised on the unit-price basis for bids in April, 1920. Only two proposals were received. As both were considerably higher than the estimates, the bids were rejected. Since it had already become evident that the project would have to be enlarged and that prices were in a very unsettled state due to post-war conditions, it was decided to revise the contract to meet these circumstances.

Accordingly a new contract was prepared to include only the deep core-wall and such upper portions of the dam as could be adapted to enlarged plans which they developed. To protect the District against a falling market for materials, an alternative form of contract was devised, modeled somewhat on a form used by other public bodies who had successfully prosecuted construction work during the war, when price conditions were very unstable. Bids were also received on the regular unit-price basis.

Form of Contract 2A. The form of contract under Proposal A provided that the Commission should pay the actual cost of the work plus a percentage fee; this fee to be increased or decreased according as the cost of the work was less or greater than the preëstablished price. The work was divided into 26 items, and a price was set for each. Most of these so-called "base-unit prices" were estimated upon a definite wage rate for common labor and were subject to adjustment in proportion to any fluctuations that might occur in the common-labor base-wage-rate during the life of the contract.

The sum of the base-unit prices times the estimated approximate quantities for the respective items, gave an estimated price upon which the contractor bid his percentage compensation fee. The sum of the adjusted base-unit prices times the respective quantities actually constructed would give the established base price, which would be used in connection with the actual cost to determine the compensation fee to be finally paid.

The cost of the work was divided into classes, viz.: (1) Elements over which the contractor would have a large measure of control by virtue of his experience, organizing-ability and efficiency; briefly, to comprise labor, rental of plant, power, fuel and the basic materials. (2) Minor elements, the cost of which would be largely beyond the control of the contractor; briefly, to comprise freight, traveling expenses for employees, miscellaneous materials, tools and supplies. (3) Expenses entirely within the control of the contractor, such as salary and personal expenses of the contractor, executive officers and officials and general overhead charge.

The Commission was to pay all legitimate charges against the actual construction cost of the work as outlined under (1) and (2), but expenses outlined under (3) were to be paid by the contractor out of his fee.

The contractor's compensation fee was also divided into classes, viz.: (1) The fee bid by the contractor which was to be paid at the bid percentage-rate against the Class 1 construction cost, providing the latter be equal to the base price; but was to be increased or decreased accordingly, should the Class 1 construction cost be less or greater than the base price. The contractor's fee was not to be reduced below 4 per cent. for reason of any such increased cost. (2) A flat 4 per cent. on all expenditures for Class 2 construction cost.

The contract was awarded to W. H. Gahagan, Inc., on November 9, 1920, on a bid of 4 per cent.

Construction Included in Contract 2A. The work included in Contract 2A consisted of the preliminary, subsurface and appurtenant work in connection with the construction of Raymond Dam. Buildings formerly used and owned by the Wanaque River Paper Company and on the site of the dam were to be demolished, others moved and set on new foundations, and a railroad siding and cantonment for laborers built before the work on the dam could be undertaken. The main work consisted of a concrete core-wall, or impervious cut-off, about 940 ft. long extending from the surface of the ground to bedrock, a depth at the lowest point of 100 ft. Other work to be carried on simultaneously with, or subsequent to, the core-wall construction was the building of portions of the dam embankments and stream-control structures. The contract provided that the minimum flow of the Wanaque River be maintained as required in the grant to the Commission and that acceptable provision be made for safely conveying the ordinary and flood flows across or around the works under construction in such a manner as to protect the work from interruption, and the structures from flooding or damage. By the terms of purchase of the real estate of the

Wanaque River Paper Company, the company was allowed to manufacture paper until April 1, 1921; consequently the contract forbade the contractor from interfering with or fouling the water in the head race, or obstructing the flow in the tail race.

Active work began at once in remodelling certain of the paper-mill buildings for purpose of barracks, commissary and shops. A railroad siding was constructed, and during the winter of 1920–1921, a steam shovel was put to work opening up the top part of the core-wall excavation which consisted of a stretch of open cut having a bottom width of 65 ft., side slopes of 1 on 1½ and about 15 ft. deep. This provided an approximately level floor at El. 212.0 upon which to operate the pile-driving rigs.

Excavation. By the time the paper company had entirely vacated its premises, excavation in open cut had progressed as far south as the mill buildings, and their demolition was undertaken, mainly with explosives as the foundations were very massive. The material that had been excavated prior to encountering the mill buildings was placed in approximately 12-in. layers within the area of the downstream embankment upon a base previously cleared. Throughout the length of the mill buildings, all the material excavated was spoiled at a place selected on the upstream side of the dam on account of the large quantities of debris it contained. When the task of demolition was completed, a deposit of paper-mill sludge, a super-fine clayey substance washed out of old paper in the paper-making process, containing a high percentage of organic matter and unsuitable for a dam foundation, was excavated from an old settling basin within the limits of the future dam.

Core-wall. As soon as the excavation of the open cut had progressed to an extent to afford sufficient working room, the frames for guiding the piling and the two pile-driving rigs were erected, one on each side of the trench. These rigs had an A-frame 75 ft. high, with an extension to a total height of 92 ft., giving a clearance sufficient to handle and mesh one 50-ft. pile into another when the latter had been driven about 10 ft. Rigs were equipped with Warrington No. 1 steam hammers and were mounted on skids, sliding on sills laid normal to the trench. The type of sheeting was the Lackawanna, arch-web, 35-lb. section. In driving the piling, the method used was to put the sheeting down as a wall and not as a series of individual piles. First a portable, timber guide frame, 48-ft. long, was set up over the deepest part of the trench. This frame was constructed so that it could be adjusted to various widths. Since it was the aim to obtain a trench 20 ft. wide at the bottom and there was no experience upon which to determine the probable deviation of sheeting for such deep driving, the guide frame was first set to a width of 22 ft. After the piling was driven, the average top width was actually found to be 21.5 ft. The deviation from the vertical at the rock was found to be about 6 in. for each wall of piling, sometimes wider and sometimes narrower than the width at the top. On top of the rock, the slope of the ledge forced the piling out of line, so that the narrowest

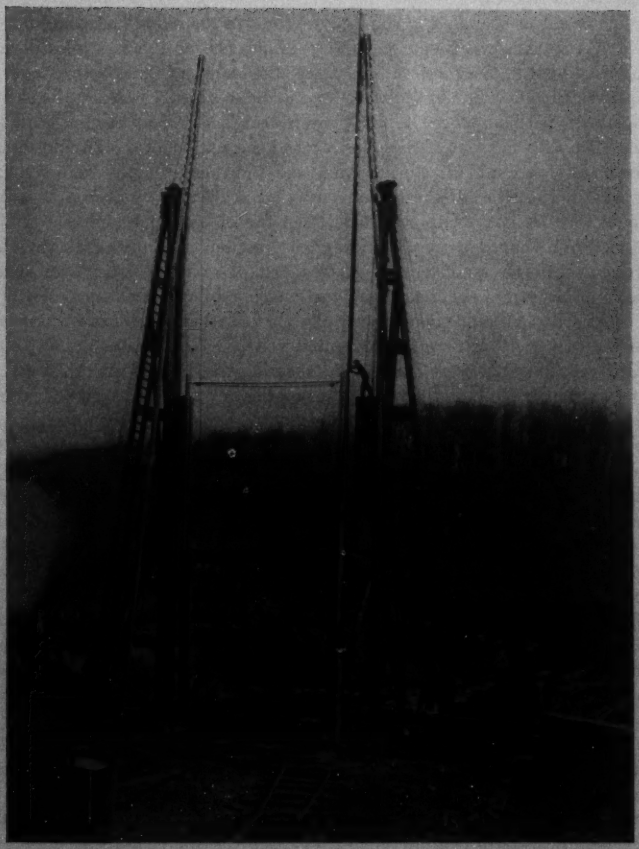

FIG. 4.— RAYMOND DAM.
PLACING FIRST STEEL SHEET-PILING FOR CORE-WALL TRENCH APRIL 2, 1921.
Showing portable guide frame and pile-driving rigs.

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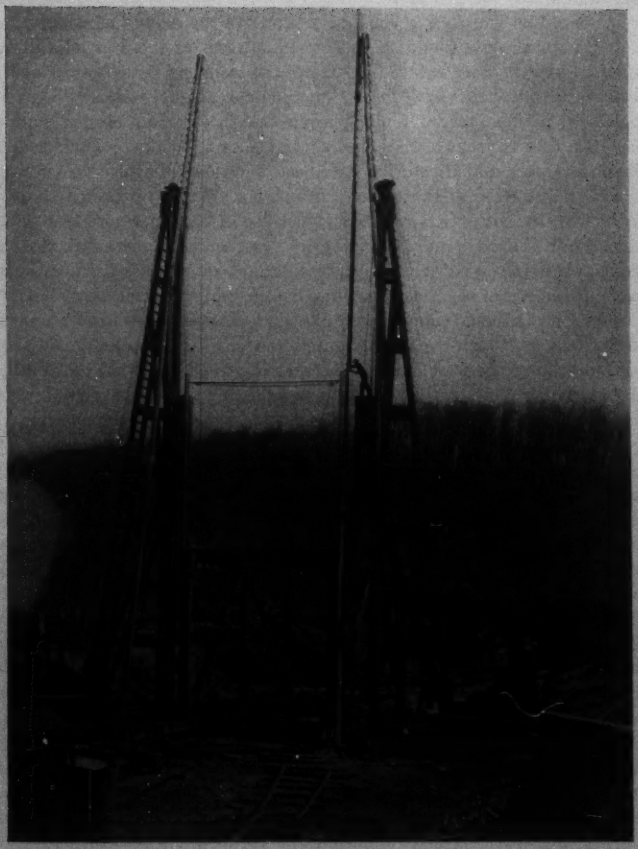

FIG. 4.— RAYMOND DAM.
PLACING FIRST STEEL SHEET-PILING FOR CORE-WALL TRENCH APRIL 2, 1921.
Showing portable guide frame and pile-driving rigs.

trench was 18.6 ft. and the widest was 24.4 ft. With this experience to govern, and for the shallower trench, the width was reduced later on to 14 ft.

A wall of 50-ft. steel piling was set up on each side of the guide frame and driven into the ground a few feet, so as to hold the toe in place. Extreme care was exercised in the first set to have the piling true and plumb. This precaution was found to be very important, as the first piles driven serve as pilots for all succeeding piles. Succeeding frames were set with equal care. Driving was begun at the middle of the set, working the sheeting down with no pile extending more than a few feet deeper than its neighbor. As the tops of the piles reached the surface of the ground, additional sets were added at either end, and additional lengths were spliced, as required, on top of the driven piling. By gradually working the wall down with its bottom to a slanting line, one of the steel members finally came up on the ledge rock. Driving to rock then continued until the outcrop at the north end of the dam was reached. Driving was then transferred to the other end of the first frame and continued for the southerly portion.

As soon as the driving was completed at the north end, excavation was begun with clam-shell buckets, operated from stiff-leg derricks running on a track on top of the west bank. The sheeting was braced with 12 x 12-in. timber in bays 10 ft. on centers with the wales and braces spaced 6 ft. apart vertically for the upper 32 ft. of the trench. Below this, the spacing was reduced. Pumping was required immediately after the installation of the top set of bracing. Two 8-in. discharge, Morris Machine Co., 60-in. diameter, centrifugal dredge-pumps were installed and dredged a considerable yardage of sand and gravel out of the trench, depositing it on the downstream dam embankment besides pumping water. In addition the following pumping equipment was used: Four No. 9 Pulsometers; two 5-in. Emersons; two Lawrence 5-in. electric centrifugals; and one Worthington electric 100-h.p., 6-in. discharge, centrifugal. In general, the contact of the steel piling with the rock surface was found to be most satisfactory, but in a few places the piling had encountered rock fragments near the bottom and had been twisted out of its interlock. There were a few piles that had been overdriven and "fish-hooked."

As soon as the earth was excavated from the northerly end of the trench, the concreting of the core-wall was begun. Aggregate was obtained from a gravel bank on the opposite side of the river, located on a terrace about 35 ft. above river level, about one-half mile away from the core-wall. The material was excavated by means of a steam shovel and was hauled to and run through a crusher and a revolving screen. The portion of the output of the screening plant that could be used at once was hauled directly to the concrete mixer. The remainder was stored in the excavated part of the pit for future use. There was about 50 per cent. of excess sand in the pit which had to be wasted. The concrete mixing plant, located 300 ft. from the core-wall trench, consisted of aggregate storage-piles feeding into bins by a derrick and two Ransome, size 53, mixers. Mixed concrete was deposited

FIG. 5.— STEEL SHEET-PILING FOR CORE-WALL TRENCH AT RAYMOND DAM. Looking north, showing method of driving in successive steps, June 16, 1921.

FIG. 6.— CORE-WALL TRENCH, RAYMOND DAM, AUGUST 1, 1921.

in bottom-dump buckets, hauled to the core-wall trench on narrow-gage flat cars and transferred by stiff-leg derricks to the concrete forms. In the bottom of the trench, on account of the interference of timbering, concrete was placed through hoppers feeding into a vertical 10-in. steel pipe.

At first the water in the bottom was handled with no difficulty by means of blind drains on the sides of the trench, but as the deeper portion

FIG. 7.— RAYMOND DAM.
CONTACT OF STEEL PILES WITH ROCK IN BOTTOM OF CORE-WALL TRENCH.

of the trench was reached, the quantity of water increased, and the ground water back of the sheeting began to leak through and flow onto the concrete. To obviate this trouble, holes were burned in the sheeting near the bottom, and 2-in. pointed and perforated pipes, 3 or 4 ft. long, were driven into the earth back of the sheeting. These bleeder pipes drained the water away from the back of the piling so that the flow into the trench was largely confined to the pipes and was easily controlled.

Concreting was carried on from the north end of the trench towards the middle, until the deepest point in the excavation was reached (Station 5+00), where the principal pumping plant was located. Operations were then undertaken part way across the valley, near Sta. 7+50, at a point where there was a natural sump in the rock. Here another pump was installed, and operations by the same methods as used before were continued in the opposite direction, until the gap between the new pump and the main pumping plant was filled. Then the closure at the deep place was undertaken, the space between the finished sections of core-wall being about 40 ft.

The method of driving and excavating the trench and filling with concrete has been described in more detail before this Association in a paper* presented by the writer on September 13, 1922. The core-wall was

*JOUR. N. E. W. W. A., Vol. 36, 1922.

finished to El. 240, the level of the floor of the valley opposite from the river, in November, 1922.

The refill of the open cut above the sheeted trench was of gravel for the downstream side and fine surface soil for the upstream portion. The latter material was obtained from the flats along the river within the reservoir. The excavation was done by steam shovel, loading cars that dumped

FIG. 8.— RAYMOND DAM.
CHARACTER OF ROCK AT BOTTOM OF DEEP CORE-WALL TRENCH.
Timbers at top of picture are cross-braces between the two walls of steel sheet-piling, April 11, 1922.

into pockets within reach of the traveling stiff-leg derrick at the dam. This derrick had been used to handle the sheeting and concrete. The material was dug from these pockets with a clam-shell bucket and deposited on the banks, spread by hand and rolled. This portion of the work was finished July 30, 1923.

Downstream Embankment. For the refill and embankment on the downstream side of the core-wall, a cut was opened in a gravel bank adjacent to that from which the concrete aggregate was obtained. A spur was laid from the existing narrow-gage track from the aggregate screens, and the railroad-type steam shovel began the excavation which finally reached a depth of 15 ft., a width of 140 ft., and a length of 1 200 ft. Until the space between the piling and the wall and a part of the open cut had been refilled, the material was transported and dumped near the derricks, which cast it over the wall with clam-shell buckets. At the same time, material was brought in by trains over a track laid around the south end of the core-wall and was dumped in the area of the former mill-sludge settling basin. Later, after pumping in the core-wall trench had ceased, a dredge pump was set up at the bend in the river near the water's edge and used to pump gravel,

brought in by cars, to the downstream refill and embankment. Some 7 500 cu. yd. of material were placed in this manner between September 1 and October 11, 1922, when the method was abandoned. After a sufficient amount of material had been placed to make it possible to reach the embankment with a track carried around the north end of the dam and along the sidehill, this was done. The remainder of the embankment was then

FIG. 9.— CORE-WALL OF RAYMOND DAM.
Constructed above the top of core-wall trench. Built of concrete in successive steps. Portion of steel sheet-piling can be seen in center of view at bottom. Pile-driving rig in upper left corner.

built by this means. Material brought in by cars was compacted with water ejected from a 2½-in. hose pipe under 100-lb. per sq. in. pressure. This practice also served to sluice away the dumped material and avoided considerable track jacking. By May 12, 1923, as much material had been placed as could be contained within the limits of the core-wall and the embankment slope.

Stream-Control Channel. Due to the proposed increase in size of the reservoir to El. 300, the design of the stream-control works was changed from an open channel to a covered conduit. Though the new design represented a departure from the type of structure that the contractor had contracted to build, he undertook the construction of the more complicated structure without modification of the contract.

The construction of the stream-control conduits, the foundation of the upper gatehouse, and the intake was started on May 15, 1923. The plan adopted was to build the upper conduit and one-half of the upper gatehouse, divert the river through it by means of a wooden crib and steel sheet-pile dam, and then to build the lower conduit and remaining half of the gatehouse. The building of this diversion dam involved the placing of some

14 500 cu. yd. of fill which eventually became a part of the embankment of Raymond Dam.

Construction of the conduits was carried out by three derricks, a narrow-gage railroad and the concrete plant used for core-wall construction, the derricks being moved to the most convenient location. The narrow-gage track was extended along the edge of the river to provide a means for carrying away excavated earth and rock and for bringing in concrete.

Stream-Control Conduits. Earth and rock excavation for the upper conduit started at the east end and progressed westerly in advance of the traveling stiff-leg derrick, which straddled the conduits and was only required to handle the final excavation, forms and concrete. The rock was drilled with jack hammers, and excavation was done by pick and shovel, the material being loaded into buckets or skips which were dumped into waiting 4-cu. yd. cars on the north side of the river. The transportation of these buckets or skips from one side of the river to the other was accomplished by means of a stiff-leg derrick rigged as a cableway. A considerable amount of excavation was removed by means of a track laid on the slope west of the conduit intake. Loaded cars were pulled by a hoist engine to the top, where the material was dumped down the sidehill.

Concreting was started immediately after a short section of excavation had been completed. Wooden forms 30 ft. long were used, one for the invert and the other for the arch; the latter being hinged at the top in such a manner that the sides could be folded inwards. After collapsing, the whole form was rolled forward as a unit upon the invert previously poured. The sides were then pushed outwards and jacked to exact line and grade. The outside forms were built in panels and were handled by the traveling derrick. Special forms were built for the upper gatehouse, the intake, and the curves in the conduit. Two trains, each hauling two 2-cu. yd. bottom-dump buckets, were employed in the transportation of the concrete. The upper gatehouse was poured by again using the derrick on the north bank of the river as a cableway, this time specially rigged to withstand the service demanded of it. As constructed, the diverting dam consisted of a wall of steel sheet-piling salvaged from the core-wall operations, braced from piles, and a gravity earth-filled crib section to connect up with the center wall of the intake. A sluiceway provided for the passage of the river until it was desired to divert its flow. A section of the dam, 100 ft. long, was left 2 ft. lower than the remainder and was equipped with an apron to take care of floods greater than the capacity of one conduit. The diversion of the river took place on October 8, 1923, and all the stream-control work under this contract was finished on February 29, 1924.

Contract 7. Due to the possibility of still further changes in the design of Raymond Dam (for it must be remembered that the final participants had not yet signed contracts), and on account of the success in meeting changed conditions experienced in Contract 2A, the succeeding contract, No. 7, was written in the same form as Alternative A in the earlier contract.

The work included in Contract 7 involved the completion of Raymond Dam, the construction of the four Green Swamp Dams, Wolf Den Dam, the overflow weir, the stretch of aqueduct immediately adjacent to Wanaque Reservoir, consisting of a short tunnel, and various appurtenances necessary to these structures. The contract was awarded to the Clifford F. MacEvoy Company of Newark, N. J., on March 10, 1924, the lowest of five bidders, on the basis of a bid of zero per cent. for Class 1 construction cost.

The Raymond Dam, overflow weir, tunnel and Wolf Den Dam constitute a group of structures near the village of Wanaque. The overflow weir is located but a short distance southwest and the Wolf Den Dam about three-quarters of a mile distant in the same direction. The Green Swamp Dams are a second group of structures located about two miles southwest of Raymond Dam. The reservoir bottom between these two groups of structures is rolling terrain, partially wooded and divided by several meandering brooks.

Stream-Control Conduits. One of the first operations necessary under this contract was the completion of the stream-control conduits, in order not only to provide for the continued control of the river, but also to enable the placing of the earth embankment uniformly across the entire length of the dam. The earth and rock excavation for these conduits was continued from the point at which they were left by the previous contractor, and the first 30-ft. concrete section to be built under this contract was ready for pouring on June 15, 1924. The sections of the conduits were built in two operations, invert and arch, and the same wooden forms were used as in the previous contract, these being by the terms of the cost-plus-fee contract, the property of the Commission.

The building of these conduits and also of the lower gatehouse was pushed with energy but with difficulty through the rigorous winter of 1924–1925. The excavation to rock was some 4 or 5 ft. below the surface of the immediately adjacent river, and continual pumping was necessary. Time and again the pumps would freeze at night, and the excavation would be found in the morning filled with water and covered by a thick layer of ice. Again, during the early thaws in February and the quick run-off of rains from the frozen ground, the Wanaque River rose and overflowed its banks, and cakes of ice 8 in. thick, floating in the swiftly moving stream all but carried away many of the forms for the lower gatehouse. In placing the concrete, the usual precautions were taken as to heating materials and protecting the setting masonry. This work was finally completed, and the Wanaque River was turned into the completed stream-control conduits and the partially-completed lower gatehouse in May, 1925.

Belt Conveyors. On account of the local conditions and the restricted area in the vicinity of Raymond Dam, the belt-conveyor system of haulage was adopted. The principal source of material for the impervious fill for the upstream portion of the dam under Contract 7 was located some 3 000 ft. east of the main dam; the intervening distance being intersected by a

river, a railroad, a busy highway and the core-wall of the dam itself. Gravel and sand, used for the general fill on the downstream side of the dam as well as for that upstream and also for concrete aggregate, was obtained from borrow pits about one-half mile upstream from the dam, adjacent to areas previously developed within the site of the reservoir under Contract 2A. Thus all downstream material, and a large proportion of upstream material,

FIG. 10.— RAYMOND DAM, AUGUST 11, 1924.
Looking from south end showing end of conveyor bringing impervious material from borrow area and method of distributing same by trucks.

required transportation across or around the core-wall. Belt conveyors were especially well adapted to meet these conditions.

The conveyor consisted of rubber-and-cotton-fabric belts running on rollers supported on a light trestle. Belts are not required to be level or to run at a uniform grade — there were inclines as steep as 20 deg. on this job. It is essential, however, that the conveyor be run in straight lines. Where an angle in the line of the conveyor is necessary, it is made by ending the first line of belt, discharging its contents into a hopper which redischarges upon a second belt, making any desired angle with the first. At each transfer point, the belt passes over a large pulley which operates as a drive pulley, the power for which is furnished by an electric motor. The weight per running-foot of the loaded belt is not great, being only that of about $\frac{1}{4}$ cu. ft. of earth, plus the weight of the belt itself, and the weight of the rollers. Workmen walking along the trestle in order to reach any point of the belt weigh considerably more than the belt itself. This practically determines the necessary strength of the trestle. The trestle in this case was constructed

of two 2 x 8-in. planks on edge, with a 12-ft. span between trestle bents, each bent being made of two posts, cross-braced together and to adjoining bents. Cedar and other trees, removed in clearing the land, were used for posts; trees as small as 2 in. at the smaller end were found sufficiently strong.

The pull that causes the travel of the belt is all exerted at the forward end; but in spite of this, the belt stretches very little in operation. There is an adjustment motion of 2 ft. of the free pulley, allowing for a 4-ft. stretch of the belt. At two points the conveyor crossed the river on simple suspension bridges, no care being taken to make the floor of the bridge level. The conveyor was carried underneath the main highway through an existing box culvert. Special construction was necessary at the two ends of the conveyor, where earth was received or discharged. At the former point a short length of belt traveled underneath the hopper under the dumping platform, where the weight of a considerable mass of earth pressed down upon the belt. A motor was used for operating this length alone and, by means of a chain belt connecting the pulleys at the two ends of the conveyor belt, power was applied to it at both these points. When power was applied at one end only, there was found to be insufficient frictional resistance between belt and pulley.

At the other end of the conveyor which crossed over the core-wall, the belt rose at an angle of about 20 deg.; the upper end with the drive pulley and motor being supported on a tower. From there a chute carried the earth at an angle of about 45 deg. into a divided elevated hopper bin. At first, a metal chute was used at this point, but it was found that, in spite of the considerable angle, the earth would not flow freely if at all damp. A belt conveyor about 50 ft. long was, therefore, placed in the chute. As very little power was required to operate it, it was driven by the same motor that drove the rising belt. The belt traveled at a rate of 400 ft. per min., and the feed hopper was designed to feed earth to it at the rate of 4 cu. yd. per min.

The conveyor system, used in connection with Raymond Dam, consisted of three sets of belt conveyors. The first, made up of four 20-in. belts, aggregating 2 800 ft., extended from the dam to the easterly area and was used for handling the impervious upstream embankment material previously mentioned. The second, totaling 5 200 ft. in length, mostly 32 in. wide, extended from the borrow pits west of the dam to the high ground at the south end and then on a light steel trestle running for its full length along the center-line of the dam. This set was used for handling the gravel for general embankment and for concrete. The third set of conveyors was used for transporting concrete materials to and from storage bins and concrete storehouse and to the mixing plant. It consisted of eleven 20-in. belts, having a total length of about 4 600 ft. Stretches of the 20-in. belt-lines were subsequently reinstalled at the other dams after serving in their first location.

The trestle on the dam consisted of 29 towers made up of two trusses,

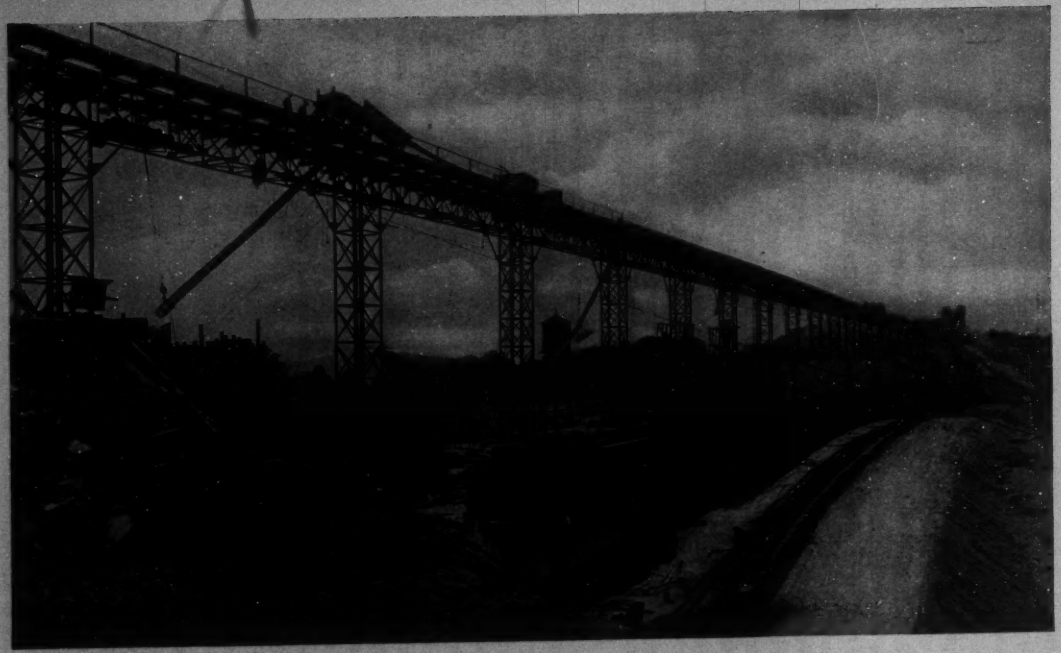

FIG. 11.— BELT CONVEYOR TRESTLE, RAYMOND DAM, JULY, 1925.
Two parallel distributing belts traveling along this trestle handled concrete materials as well as embankment materials for both sides of dam.

each 5 ft. deep, with chords consisting of 6 x 6 x $\frac{3}{8}$-in. angle bars. Twenty of these towers, on 50-ft. centers, rested on the concrete core-wall foundation put in under Contract 2A. The remainder rested on especially-poured concrete bases. The intervening spaces were bridged by double trusses 5 ft. deep on 5-ft. centers. The chords of these consisted of $3\frac{1}{2}$ x $2\frac{1}{2}$ x $\frac{5}{16}$-in. angle bars, and the whole structure was guyed by steel cables.

The trestle was surmounted by a deck carrying two conveyor belts, 32 in. and 20 in. wide and having the necessary motor units, trippers, etc. The top of the trestle was at El. 318, 13 ft. above the top of the core-wall and 3 ft. above the eventual top of the fill. The towers were built into the concrete as the core-wall construction progressed, but the trusses were salvaged after the fill had been placed.

The power used for driving the belts was 3-phase, 2 300-volt, 60-cycle alternating current supplied to the contractor's plant at the dam by the Jersey Central Power & Light Company. For all the exposed, secondary motors, the current was transformed to 440 volts, while the higher voltage was used directly on all large enclosed motors. About 100 h.p. were required for a line 2 800 ft. long. With the exception of steam shovels and such equipment as trucks and tractors, electric power was used throughout this contract.

Rolled Embankment. The placing of the rolled embankment of selected material on the upstream side of Raymond Dam was begun in June, 1924. The material was top-soil from the east area previously described in connection with the belt conveyors. The removal of soil from this area was accomplished in the main by elevating graders. An Austin, New Era Senior, grader, drawn by a Holt, 10-ton "Caterpillar," tractor delivered the dirt in a continuous stream into 120-cu. ft. bottom-dump trailers. A train of three of these was drawn along by a Holt tractor parallel with the grader and at the same speed. When the three trailers had been filled, they were drawn to a dumping platform where they were dumped into a hopper, then returning for another load. Three caterpillar tractors, each hauling three trailers, kept the grader in continuous operation, except for a few seconds when one train was drawing away and another taking its place, and for the time taken (about two minutes) in turning the grader at the end of the field and starting back again.

The tractor was operated by one man, and two more were required for the grader, making six in all. At the dumping platform there were three or four men dumping the trailers, keeping the platform clean and doing what was necessary to keep the dirt flowing continuously from the hopper to the belt beneath. This gang, in the season of 1924, averaged about 800 cu. yd. of loose dirt a day, equivalent to about 700 cu. yd. of soil as it lay, and about 600 cu. yd. of compacted embankment. When everything worked smoothly, this amount of excavation was often doubled, but there were occasional delays.

The impervious material was distributed on the embankment by

means of five 4-cu. yd. trucks loaded from underneath the bin at the end of the belt conveyor. Loading required about 50 seconds. The trucks were self-dumping with tailboards fastened to be partly opened, so that when the truck traveled with the body in the dumping position, the load was spread more or less as it was dumped. It was further spread to a thickness of about 6 in. by two, Wehr, one-man gasoline-power graders. Meanwhile a man with a wheelbarrow removed from the dumped material all roots or other vegetable matter of any size. After having been spread, the material was rolled with two 10-ton rollers having the front wheel grooved and the two rear wheels flat. A small street sprinkler wet the rolled embankment just before new material was spread upon it, when the incoming material was not sufficiently moist. The placing of the impervious embankment was continued in 1925, but the remaining material from the easterly area was excavated by steam shovels instead of elevating graders, as the fine material was in a deeper deposit. Trucks were used to transport the material to the central loading hopper, where it was fed in an even stream onto the conveying belt. The elevating graders were transferred to the flats west of the dam, where a new borrow area was opened up, and material was at first brought by truck and tractor-drawn trailers directly to the embankment. These areas were carefully prepared for stripping by cutting off all trees and brush, raking, piling and burning all organic matter, grubbing out all stumps and roots, and plowing and harrowing to completely cut up the sod. The thoroughness with which this work was done contributed in a large measure to the speed with which the successive layers of impervious fill were spread and rolled, as only a comparatively small amount of organic material had to be removed when the material reached the embankment.

Conveyor haulage had been resorted to on the east side as a means of overcoming the physical obstacles of river, railroad and highway crossings. On the west side of the dam, the same means of transportation was used to overcome the obstacle of elevation when the impervious embankment had reached a height no longer practicable for truck or tractor haulage. A large hopper was built at the east end of the borrow pit from which the general-embankment material was obtained, and into this, narrow-gage dump cars, trailers and trucks dumped their loads. A conveying-belt from this hopper fed onto the other belts previously built in this area for the conveying of general-embankment material. This operation began in August, 1925.

Throughout the spring and summer of 1925, the placing of impervious embankment was handicapped by extremely rainy weather. Not only could construction not be carried on during a rain, but, depending upon the intensity and duration of the rain, perhaps not for three days following. Because of the nature of the material, it would, when wet, stick in the various hoppers along the belt-conveyor line. The insurmountable difficulty, however, was the spreading and rolling on the wet and muddy bank. Also with slight frosts, such as occurred during April and late October or early

in November, the bank became slippery and would not hold the roller. A maximum of 150 working days suitable for the placing of the rolled embankment is all that could safely be counted on in this climate. By working double shifts during May, June and July, an average of 251 working-shifts of 8 hours each employing usually two rollers was reached for each of the years 1924 and 1925, during which this work progressed most actively at Raymond Dam. During the month in which the greatest amount of rolled embankment was placed, 18 700 cu. yd. were spread and compacted with the expenditure of 384 roller-hours of rolling. This was at the average rate of about 50 cu. yd. per hour per roller. The average daily output over the two-year active period, 1924 and 1925, was 624 cu. yd. per 8-hour shift using two rollers, or at the average rate of about 40 cu. yd. per hour per roller.

Two shifts of 8 hours each were used in the building of impervious embankment until August 1, 1925, when the work was put on a one-shift basis. Placing of embankment was continued until October 23, when wet weather and frost compelled the closing-down of this operation. The rolled embankment at the end of that season had reached an average elevation of 277.0.

The work of the 1926 season was begun on May 15 and was carried on with the same plant arrangement and force used during the latter part of 1925, except that all the material was hauled to the central hopper by narrow-gage railroad. Only one shift of 8 hours was occupied on the selected-embankment operation, but work was begun at 6 A.M., in order to allow the use of the belt conveyors for the placing of general embankment during the succeeding 8 hours. Some difficulty was experienced in manoeuvering the trucks spreading the material on the embankment, due to decreasing width as it reached a higher elevation. This was overcome by enlarging the embankment at several points to serve as turnouts. Later, as the embankment neared the completed elevation, the material was chuted off the conveyor directly into the trucks, as there was insufficient clearance for the continued use of the hopper. Throughout the season, the building of the embankment was divided into two unequal parts as a result of the construction of the retaining walls at the upper intake. The embankment was brought to the top of the core-wall, El. 305, and had been completed in all respects by July 10, 1926.

The specifications for rolled embankment required that the material be spread in layers of such thickness as to compact to a thickness of 4 in. after rolling. The thickness of the material, as it was spread loosely, varied with the character of the material but did not ordinarily run over 6 or 7 in. To compact the material, rollers were used weighing 10 tons, with 20-in. width of rear wheel, 40-in. width of front wheel and operating at a speed of about 200 ft. per min. One passage of each rear wheel over a given area was found to produce satisfactory and sufficient compacting. This is equivalent to five rollings of a given area. To guard the face of the rolled

embankment, which was built on the steep slope of 45 deg., against erosion from heavy rains, a protecting layer of gravel was placed as the work progressed.

Several tests of material placed in the rolled bank showed a weight of 135 to 140 lb. per cu. ft. in place, which is an indication of the efficiency of the rolling. The fineness of the material as indicated by the effective size ran from 0.11 to 0.17 mm. in these tests.

General Embankment. Weather and other conditions permitting, whenever the conveying system was not in use transporting concrete for the core-wall or selected material for the rolled embankment, the belts were employed to transport material for the general embankment, which could be built in all but extremely bad weather. Beginning about November 9, 1925, after the placing of impervious embankment had been discontinued, the work was placed on a two-8-hour-shift basis until December 24, when one shift only was used for the remainder of the working season. Material for the embankment was dug by a 2½-cu. yd. Bucyrus railroad-type shovel from a large borrow pit west of the dam and across the Wanaque River. The top-soil had previously been stripped from this pit for the building of the impervious embankment. A movable hopper, mounted over a belt conveyor which paralleled the cut, was used to feed the material evenly upon the belt. The belt was mounted upon a frame fitted with wheels placed normal to the belt so that, upon the completion of each cut, it could be moved sideways towards the bank. One man at each hopper controlled the flow of material upon the belt. This belt was 32 in. wide with an aggregate length of 3 855 ft. and conveyed the gravel from the shovel-cut to the large belt on the steel trestle. It was divided into six separate lengths requiring a total of 290 h.p. for operation; the 1 450 ft. of 32-in. belt on the trestle required 50 h.p.

For the upstream embankment the sand and gravel were discharged from the conveyor belt on the steel trestle into chutes extending over the impervious fill. These were supported from booms fastened to a trestle tower. For saturating it, a stream of water was played on the material as it entered the chute, and its distribution on the fill was a matter of swinging the chute occasionally from one position to another. This saturation resulted in very effective consolidation of the material. Considerable difficulty was experienced in confining the flowing material within the slope limit. Baffle boards proved ineffective. Grading the outside slope with a caterpillar steam shovel was finally resorted to. The output of belt conveyor, chutes and two shovels was only about 7 000 cu. yd. of fill a week.

The fill on the downstream side was placed by unloading from the large belt on the steel trestle and depositing through a short chute. This left a series of cones as the tripper of the belt was moved forward. Later, streams of water from fire hose were played on these piles to spread the fill out towards the toe.

Placing general embankment continued during 1926 by this method,

and the downstream slope of the embankment was completed in May, 1927. For the aërator terrace, fill was transported from the trestle to a hopper located on the aërator fill. It was then hauled to its final position by dump cars. All general embankment was completed by July, 1927.

By the belt-conveyor arrangement, the excavated sand and gravel from the borrow pit were conveyed to the south end of the dam, where devices were installed to permit the diversion of the material either onto the belt conveyors running out onto the dam, to be placed in the embankment, or onto conveyors running to the gravel screens. Excess sand from the screens, of which there was a large proportion, was conveyed back onto the dam for fill. Over-sized cobbles from the screen were allowed to accumulate on a separate storage pile.

By this method, the belt conveyors were in practically continuous use for transporting materials either for concrete or fill. During the long days, the conveyor worked two shifts.

Core-wall and Miscellaneous Structures. The building of the core-wall, which of necessity had to be completed in advance of embankment construction, was started on December 1, 1924 and finished on July 31, 1925. The old concrete-mixing plants, used on Contract 2A, were abandoned at the completion of that work, and a new plant was built for the work to be done under Contract 7, located on the top of the hill at the south end of the dam. It consisted of a screening plant for separation of the gravel, which was excavated from borrow pits in the reservoir, storage hoppers, a cement-storage shed and a belt-conveyor system for the cement, aggregates and concrete.

A Blaw-Knox traveling steel-form, 100 ft. long and 16 ft. high, was used for the main body of the core-wall, a stretch 850 ft. long and 65 ft. high. Wood-panel forms were used for the ends butting against the ledge-rock slopes. The steel form was poured in two 50-ft. sections and was then moved ahead by running it on rails, supported on brackets attached to the concrete of the lower lift. The first 50-ft. section was started on December 12, 1924.

The fourth section poured ended disastrously, due to the failure of the form. The form had been filled to a depth of 13 ft. in 6 hours of pouring, when 3 of the bottom tie-rod bolts sheared off. The bottom of the form bulged out about 2 ft. at the middle, and all the concrete flowed out through a wide breach at the bottom of the form. The average temperature of the air during the 6 hours of pouring had been around 32° F., and the concrete had apparently taken no initial set. The form was reconstructed by adding another row of tie rods 6½ ft. from the bottom; gusset plates were inserted in many places, and heavier structural members were substituted for those in place. It was not until February 14, 1925, that the form was ready for pouring again. From this time on, however, the pouring progressed with little interruption. Two consecutive days were used to pour the two halves of the form, and the third day was used for moving it. At the

end of the dam, the form was raised to the next lift by jacking with 10 threaded rods. The core-wall, with the exception of the upper gatehouse, was completed with the pouring of July 31, 1925. The concrete poured in 94 work shifts was 16 415 cu. yd. At the ends of the wall, and at the gatehouse, where special forms were required, wooden construction was used.

The concrete from the central mixing-plant at the south end of the dam

FIG. 12.— OUTLET OF STREAM-CONTROL CONDUIT — RAYMOND DAM. Both waterways completed as far as overflow channel. River flowing in its original bed through gap in core-wall and to the right of the retaining wall in right foreground. Highest portion of core-wall in left background is completed, April 27, 1925.

was chuted onto a 20-in. belt conveyor, running on the steel trestle. The concrete was tripped from this conveyor into chutes which carried it to a small hopper mounted on the form, whence it flowed by other suitably-arranged chutes into the form. Due to its more complex construction, the upper gatehouse, which is integrally a part of the core-wall, was not finished until December 8, 1925. Two retaining walls, which form the entrance to an upper intake, were started and completed in April, 1926. The wing-walls on either side of the upper gatehouse, were built in July of the same year. The building of an intermediate intake, which had been begun in October of 1925, was kept just ahead of embankment construction and was finished in April, 1926. The concrete walls of the lower gatehouse, the structure which houses the main control mechanisms, were carried up to El. 241, at which point work was suspended pending the installation of valves, operating stands, and special pipe.

Riprap. The face of the dam next to the reservoir is covered with a layer of large stone fragments, about 11 ft. thick at the bottom and 4 ft. at the top. This material was blasted out of a quarry of the local gneiss rock, opened within the reservoir area north of the overflow weir. The plant layout consisted of a 2½-cu. yd. Bucyrus railroad-type steam shovel in the quarry, narrow-gage railroad track placed on an ascending berm cut in the

FIG. 13.— UPSTREAM FACE OF WANAQUE DAM SHOWING INTAKES.
October 13, 1927, temporary bulkhead in place at entrance to lower conduit, to permit construction of rack bars to form lower intake. Entrance to upper conduit, at right, later closed with concrete plug, access to this conduit thereafter being through the middle intake chimney, the box-like structure just above. Upper intake is in gatehouse substructure at top of the picture.

face of the completed upstream slope of the dam, and two steam shovels located on the dam below the track in such a position as to be able to handle the rock as it was dumped from the cars. Very little hand work was required, two men at each shovel usually being sufficient to trim the rock to the required slope. Little or no disturbance was caused to the finished slope of the embankment by the dumping and rehandling of the rock, as this work was carried on in the winter and the slope was solidly frozen, a condition which allowed the rock to slide farther than it would have ordinarily. This aided greatly in the placing. The laying of riprap was started on December 10, 1925, and continued through the winter. By April, 1926, it had been carried to El. 267, the highest point to which the upstream general embankment had been completed up to that time. Work was resumed in December, continued through the following winter and completed in March, 1927.

FIG. 14.— RAYMOND DAM — UPSTREAM SIDE.
June 11, 1926.

Landscaping. A water-supply development, such as the Wanaque, may be made an asset to the community from the esthetic standpoint. With modern transportation facilities and habits, nearly every consumer becomes familiar with the sources of his water supply, and since it is something that materially affects his well-being, it is carefully scrutinized. The beautiful sheet of water created by the Wanaque Reservoir will be one of the scenic features of New Jersey.

The plans of the Commission provided for preserving such of these natural beauties as were within the area taken for protecting the shores of the reservoir, and for reforesting such areas as had been denuded in past years. In carrying on the construction work, the contractors were required to pursue their operations so that the beauties of nature were marred as little as possible. No unsightly borrow pits were permitted in conspicuous localities to scar the landscape.

In further harmony with this program, the landscaping of Raymond Dam itself and of the surrounding grounds was given consideration, and a firm of landscape engineers was engaged to prepare a design in keeping with the importance of a project having so wide a field of public interest. The late Charles W. Leavitt, a landscape engineer of extensive experience in the artistic treatment of water-works structures, prepared a design, the principal feature of which was the paving of the downstream face of the main dam with native stone in the form of raised arch rings. Within these arches are grassed areas. The whole treatment adds to the appearance of stability in the structure and provides an attractive background for the aërator fountain, the central feature of esthetic interest in the picture. Immediately in front of the aërator are provided a series of cascades ending in a reflecting pool near the entrance gateway. Winding drives and paths furnish adequate access for visitors and service. All the gatehouse details, walls and other structures visible from the main highway passing in front of the dam were given suitable architectural treatment in harmony with the design of the more important features, and the whole is to be set off by lawns and planted areas. To assist in planning the landscape work, a model of the landscape features and face of the dam was constructed to a scale of 20 ft. to the inch.

Downstream Paving. The principal feature of landscaping — the paving of the downstream face — was subsequently incorporated in Contract 7. Construction work on this feature was started in May, 1927. The railroad track which had been used to haul riprap to the upstream face of the dam was extended to the north end of the dam, where a switch-back connected with a track on top of the dam. As the construction of the latter progressed in a southerly direction, the belt conveyors on top of the dam were removed. Stone, sand and gravel for the downstream facing were transported over this railroad. Two derricks, supported by one stiff-leg and two guys, were erected on narrow berms constructed on the downstream face. One derrick was served by the track on top of the dam, and by transfer from one derrick

to the other, the bottom of the dam was reached. Stone obtained from the same quarry as the riprap, was loaded on skips on flat cars and was transferred by derrick to the face of the dam. Each derrick was mounted on a track. This facilitated movement as the stone work progressed from the northerly end towards the south. Eight masons, each with two helpers, laid the walls of the arches and the parapet walls in mortar, while gangs of

FIG. 15.— RAYMOND DAM FROM OVERFLOW CHANNEL.
November 1, 1928.

laborers placed the riprap and top-soil for the grassed areas. The masonry work was started in June, 1927, and completed in June, 1928.

Completion of Upper Gatechamber. Throughout the construction period of Raymond Dam, the Wanaque River was successfully passed by the structure through the double-barrelled concrete conduit previously described. On September 1, 1927, a flood of 3 200 sec.-ft. occurred and only filled the upper conduit a little more than halfway. The final closure of these conduits was carried out in the winter of 1927–1928. Temporary stop planks, which could be removed in case of floods, were first placed in the lower of the two conduits, and the river flow was turned into the upper in October, 1927. The rack-bar support, sluice gates and steel pipe were then installed in the section.

In January, 1928, the temporary stop planks in the lower conduit were removed, and the river was diverted through the gate openings and steel

pipe in that section. The upper conduit-opening was permanently plugged, and gates, operating mechanism and steel pipe were installed in that section. Construction work elsewhere in the reservoir was coördinated with this operation, so that no damage would be done by any winter floods that would rise in the reservoir due to the opening through the dam being restricted to a 72-in. pipe.

On March 23, 1928, the two gates serving the lower conduit were closed, and the filling of Wanaque Reservoir began.

Overflow Channel. The topography at the site of Raymond Dam permitted building the overflow weir and the upper part of the overflow channel as structures separated from the main structure by a hill of ledge rock. Below them the channel turns, passes through a ravine and joins the original river bed below the dam. The use of the natural ravine for part of the overflow channel involved, however, the removal of some 80 000 cu. yd. of earth and rock to provide a sufficient waterway and to prevent the washing-down of the overlying earth with its accompanying danger of partially filling and blocking the river bed below the dam. A gaging weir is provided in the lower channel. Where the channel is not in solid rock, the bottom is protected by massive stone-paving and the sides by stone-faced retaining walls.

Excavation of the overflow channel was begun in the ravine in July, 1925. The material was hauled to the embankment of the dam. After the excavation of some 15 000 cu. yd. of earth and rock, the lower portion of the overflow channel in the river bed below the dam was begun. A cofferdam was built down the middle of the river bed and half of the river channel completed at a time, the other half being occupied by the flowing stream.

The paving consisted of large fragments of sound, native rock procured from the same quarry as used for the riprap operation. The wall on the north side of the channel, extending from the north abutment of the Greenwood Lake highway bridge to the north portal of the tunnel, serves to protect the embankment of the lower part of the dam from damage in times of flood. This wall is faced with rectangular stone, worked from a quarry opened up adjacent to the overflow weir. Just below the overflow weir, a deep pot-hole was formed in the rock which was filled with fine silt overlaid by swamp muck. All this material was removed by steam shovel and crane, and spoiled in a waste dump outside the reservoir. About 47 000 cu. yd. of this material were removed. The hole was allowed to fill with water.

The various operations in connection with the channel excavation and improvement extended over the years 1925 to 1928.

Overflow Weir. Excavation for this structure was begun in September, 1926. Later in the fall, concreting was under way. The weir was completed in June, 1928. Concrete was mixed in the main concrete plant at Raymond Dam and conveyed to the weir by a belt conveyor, constructed of belting previously used elsewhere on the contract. This belt conveyor was subsequently extended to Wolf Den Dam.

The only unusual feature of this structure are the steel supports for the stop-plank grooves and bridge, which are imbedded in concrete. The concreting of these piers, which are of thin section and have narrow clearances, was made possible by the use of a small aggregate and Celite.

Green Swamp Dams. There being no suitable gravel-deposits near Green Swamp, concrete aggregate for these structures was hauled by motor

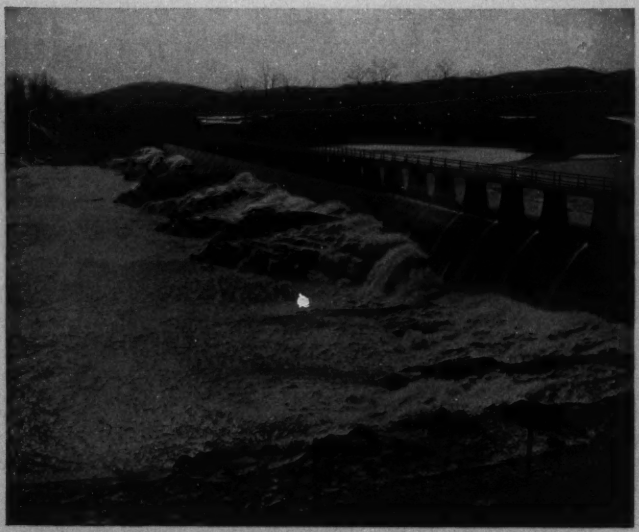

FIG. 16.— WANAQUE RESERVOIR OVERFLOW WEIR.
Reservoir filled March 5, 1929.

truck from the Raymond Dam concrete plant. A concrete-mixing plant, cement-storage house, and sand- and gravel-storage piles were placed locally on the hill between Green Swamp Dams No. 1 and No. 2, and a belt conveyor was built parallel with each dam.

Green Swamp Dam No. 1. Excavation for the core-wall at Dam No. 1 was in a timber-sheeted trench. Exploratory borings had indicated apparently substantial ledges of rock underlying the earth at an average depth of 12 ft. Upon uncovering the rock, however, it was found to be very variable in quality. The rock at this point is silicated, serpentinous, limestone modified by igneous intrusions. The differences in quality, structure and composition, when exposed to influences of weathering and erosion, presented opportunity for some very pronounced zones of decay, while solid ledge was encountered immediately adjacent. It was found necessary

in some cases, to excavate the rock to a depth of 20 ft. in order to reach a satisfactory core-wall foundation.

The embankment was of local material from borrow pits nearby. The material was excavated by elevating graders and hauled to the embankment by tractors and trailers, the finer material being selected and placed on the upstream side and rolled. Riprap was obtained from the excavation at the site of Dam No. 2.

FIG. 17.— GREEN SWAMP DAM NO. 2.
Concreting on May 18, 1925. Concrete brought from mixing plant by belt on high trestle and placed in forms from chute, shown in center of picture.

Work was started on Green Swamp Dam No. 1 in July, 1924, the core-wall was completed in June, 1925, and riprap was finished in November, 1926.

Green Swamp Dam No. 2. This is a masonry structure and was started shortly after the core-wall of Dam No. 1. The bedrock is of igneous origin with a few decay zones along the joints. In one or two instances, seams were excavated to considerable depths. Grouting was done wherever water tests of the grout holes indicated a leakage through rock fissures of 2 g.p.m. or more under a pressure of 75 lb. per sq. in. Grout holes, spaced 10 ft. longitudinally, 9 ft. transversely and staggered, were drilled to a depth of 18 ft. below El. 275 and to a depth of 10 to 15 ft. above this elevation. In deep, seamed rock another longitudinal line of holes was added, so that the entire foundation would be impregnated. A total of 14.2 cu. yd. of grout was placed in the foundation of this dam.

The masonry was poured in approximately 10-ft. lifts 30 ft. long. The concrete was delivered from the central mixing-plant by a belt conveyor on a trestle parallel to the upstream face of the dam. Concrete was unloaded from the belt by means of a tripper and delivered to the form by chuting. Split-tile drains were placed in all horizontal joints below El. 292. These drains lead into wells 2 ft. square at each vertical construction-joint. The

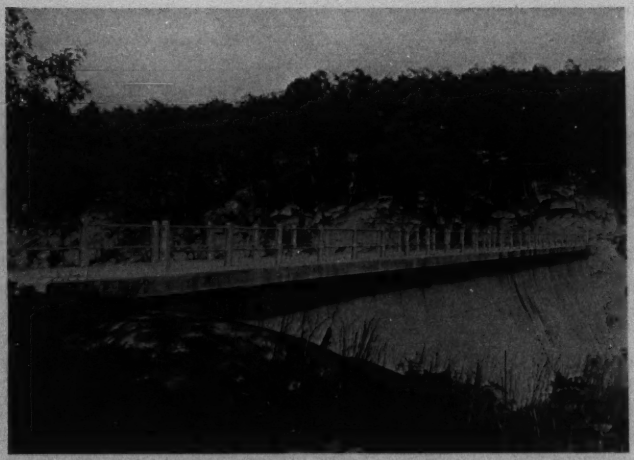

FIG. 18.— GREEN SWAMP DAM NO. 4.
Downstream, looking east. September 13, 1926.

wells are drained by 8-in. wrought-iron pipes leading to the downstream face of the dam. The outlets of these drains are concealed by a rock fill.

Wooden forms, held together by 1-in. tie rods, were used, and the bulkheads were braced against iron rods inserted in drill holes in the lower lift. A contrivance employed to move the forms forward consisted of a carriage running on 8-in. iron wheels. Running on one 10-ft. lift, this carriage was backed up against the end of a section on the lift above, which had been previously poured. The top members of this carriage consisted of 6 x 8-in. timbers with strips of wrought iron laid longitudinally to the dam, the bottom of the timbers being at the same elevation as the top of the newly-poured concrete. Similar timbers were laid on top of the new concrete in such a manner that an iron pipe could roll continuously from the timbers on the concrete to the timbers on the carriage. The moving of the form then consisted only of loosening it and suspending it on a frame work which rolled on 4-in. iron pipes on the aforementioned timbers. A hand-operated winch was used to pull it. In its new position, the form was fastened and the carriage rolled out from under.

The dam is surmounted by a coping 2 ft. thick which overhangs 6 in. on either side of the wall. The coping was separately poured in 10-ft. lengths, with an "Elastite" expansion joint between sections. The top inch of this coping is a granolithic finish, made with cement and granite screenings passing a No. 8 screen. A railing, consisting of reinforced concrete posts and 2-in. iron pipes, borders either side of the coping.

The structure was completed, except for the guard rail, in November, 1925.

Green Swamp Dam No. 3. This is a core-wall and earth-embankment structure only 18 ft. high, just east of Dam No. 2. It was completed in 1926.

Green Swamp Dam No. 4. This is a short concrete structure similar in section to Dam No. 2. The excavation was in a deep, sheeted trench and was made by means of a clam-shell bucket operated from a stiff-leg derrick. At the deepest point, ledge rock was 30 ft. below the surface. Most of the ledge was found to be solid, only a small amount being excavated to provide an acceptable foundation.

The concrete for this dam was mixed at the plant used for Dam No. 2, was conveyed by belt to Dam No. 3, and then taken in bottom-dump buckets by narrow-gage railroad to Dam No. 4. The construction was carried on during 1925 and was completed in the summer of 1926.

Wolf Den Dam. Wolf Den Dam, an earth structure with concrete core-wall, was started during July, 1925. Concrete was transported by a 20-in. belt-conveyor line, extending from the concrete-mixing plant at Raymond Dam to the easterly end of Wolf Den Dam and then along the downstream side of the core-wall. On this belt, concrete for the core-wall, impervious material for the soil core, and gravel for the general embankment were brought from Raymond Dam. Compressed air and water were piped from Raymond Dam. The foundation presented no difficulties. Concrete for this structure was transported a maximum distance of 3 200 ft., the longest belt-conveyor concrete-haul on the job. In very hot weather, additional water was added to the concrete by sprinklers along the way. Otherwise, no special precautions were taken, and the workmanship was satisfactory. It should be stated, however, that this is about the limit for this type of operation. Riprap was obtained from the same quarry as for Raymond Dam, and was hauled by narrow-gage railroad along the top of the dam. This structure was finished in July, 1927.

Grassing Slopes of Dams. The gravel embankments of the dams at the Wanaque Reservoir, covered with only a thin layer of top-soil, present a problem with respect to seeding for a good stand of grass to withstand the severe conditions on the dry, exposed slopes. Consultation with grass experts resulted in the adoption of Mapes General Crop Fertilizer, applied at the rate of 1 000 lb. per acre, and of a mixture of Canada blue grass, orchard grass and red fescue (5 parts each), sheep fescue (2 parts), and red top (3 parts), applied at the rate of 50 lb. per acre. The results obtained have been satisfactory.

FIG. 19.— WANAQUE RESERVOIR — WOLF DEN DAM.
Placing impervious material on reservoir side of concrete core-wall August 2, 1926.

Relocation of Highways and Railroad.

The principal highway disturbed by the construction of the reservoir was the Pompton-Greenwood-Lake Turnpike, the most direct and convenient road leading to Greenwood Lake from the south. It also connects with the Sloatsburg Road, which provides access from the region in the vicinity of the reservoir to the West Shore Hudson Highway and is an important link in the route from New Jersey to the Catskills. The former

Fig. 20.— Wanaque Reservoir — Wolf Den Dam.
May 5, 1926. Looking east, showing section of completed core-wall and belt conveyor on downstream side, for transportation of concrete and embankment material.

was a county highway with a permanent 18-ft. pavement, and both carried a heavy tourist traffic throughout most of the year. West Brook Road was a secondary, borough road, leading from the Greenwood Lake Road westerly across the Wanaque Valley. While carrying very little traffic previous to the construction of the reservoir, it provides the only practicable access from the south to a large territory for which it was necessary to plan some means of access. In all, about 10.3 miles of county and borough highways were closed after the completion of about 8 miles of highways by the Commission.

The New York and Greenwood Lake Division of the Erie Railroad enters the reservoir area at a point about 2 miles north of Raymond Dam. Originally it ran parallel to the Wanaque River from that point to Greenwood Lake, a distance of 11.2 miles. Of this distance, approximately 3.6

miles of the railroad lay within the area of the reservoir and required relocation, together with about 1.5 miles of the Ringwood Branch.

The studies of this problem showed the desirability of designing the railroad and highway relocations in conjunction with each other, so as to reduce the number of grade crossings to a minimum, to improve the visibility conditions at such grade crossings as were unavoidable, and to combine the structures so far as practicable.

The roadways and other structures were designed to be adequate for present-day conditions and as nearly permanent in character as possible, even though in some instances the existing works were not entirely up-to-date nor in the best of repair. This policy was adopted because within the watershed, at least, the provision of adequate and permanent substitutes for the properties abandoned will reduce greatly the need for extensions, changes and repairs, with their attendant possible bad effects on the water in the reservoir. After the reservoir is completed, the less conditions are disturbed, the better for the water supply.

The minimum elevation for the relocated roads and railroad was fixed at 8 ft. above the flow-line, in order to provide assurance that roadways would be at all times above high water, even under flood conditions more severe than ever recorded in this vicinity. The selection of the railroad line along the easterly side of the reservoir resulted in the adoption of a line for the Greenwood Lake Road lying east of and in some cases adjacent to the railroad, following in general the easterly shore of the reservoir.

The standards of the State Highway Commission for first-class highways were adopted, calling for grades not in excess of 5 per cent. curves of not less than 955-ft. radius, and permitting a clear vision of at least 350 ft. at all times. The roadway was originally planned to be 30 ft. wide, with a 20-ft. width of permanent pavement. At the request of the Board of Freeholders of Passaic County, it was finally decided, on account of the increasing traffic, to build both the roadways of Greenwood Lake and Ringwood roads 36 ft. wide, and to provide a pavement 24 ft. in width. The cost of the extra grading and the new surfacing was met by the county. West Brook Road was graded 18 ft. wide with a 15-ft. gravel surfacing. All highways, when completed, were taken over by the county or local authorities for future maintenance.

Railroad. The portion of the Erie Railroad affected by the construction of the reservoir falls under Class C of the usual traffic classification, so that in accordance with standard railway practice, the type of roadbed used for main-line traffic was not required. The maximum gradient within the reservoir was 1.4 per cent. north-bound on the main line and 1.8 per cent. on the Ringwood Branch. The sharpest curve had a radius of 500 ft. It was decided that the most equitable solution of the problem would be to select the cheapest line acceptable to the Railroad Company, construct the new road at the expense of the Commission and compensate the Company for all contingent expenses and added costs caused by the relocation.

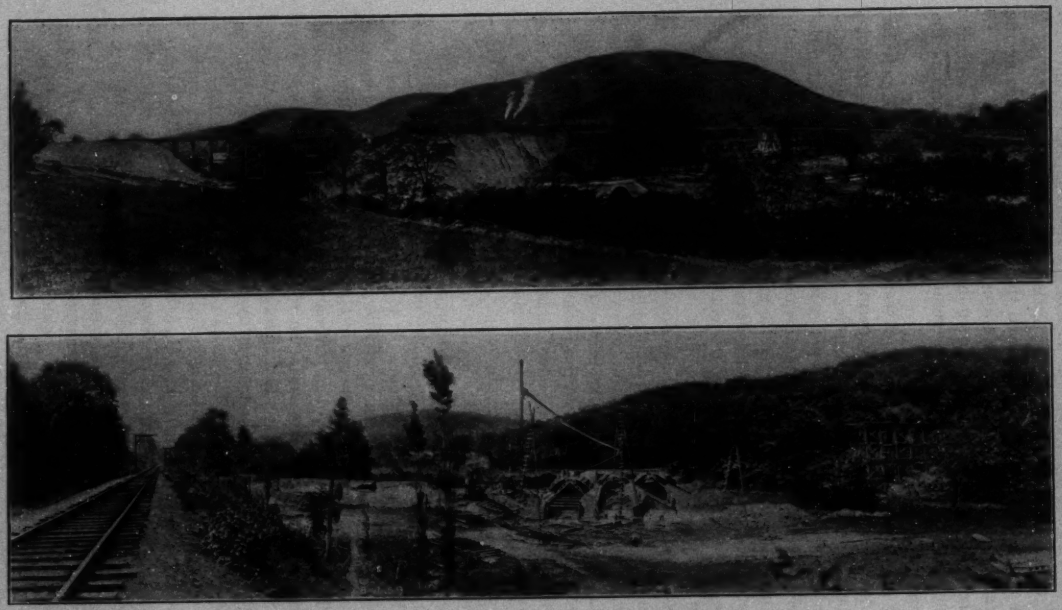

FIG. 21.—WANAQUE RESERVOIR — RELOCATION OF ERIE RAILROAD AND CONSTRUCTION OF LARGE FILLS WITH CULVERTS.

Upper: June 4, 1926, constructing Ringwood fill from temporary trestle, Ringwood Culvert in center.

Lower: July 8, 1926, beginning Wanaque fill, with construction of three-barrel culvert to take flow of Wanaque River. Top of fill to be at height of trestle at right over Greenwood Lake Road.

A railroad line was laid out by the Commission's engineers and was accepted, together with typical sections, by the Railroad Company, after minor changes in location and grades in the interest of construction and operating economies. It was admitted by the Railroad Company that the probability of double tracking was remote, so the only provision made for this was a widening of the lower portion of the fills in the deeper portions of the reservoir.

In order to eliminate, so far as possible, the necessity of repairs to bridges and culverts within the reservoir, these structures were planned entirely of concrete of conservative design. Since these structures are more nearly permanent than those on the original line, thus requiring less expenditure by the Railroad Company for repairs and renewals, a credit was allowed the Commission for this item. The Commission also received credit for decreased maintenance cost due to elimination of some minor grade crossings.

It was agreed that the track work for the new line would be carried out as follows:

New rails to be furnished at expense of the Railroad Company; cost of ties to be shared by both parties; cost of laying new line, including ballast, and of removing old track, to be paid by Commission; all track work to be performed by Railroad Company forces at cost.

The discussion between the engineers of the Railroad and the Commission as to the amount of compensation due the Erie for increased operating costs on the new line hinged primarily on the question of probable future traffic. The other elements used in determining the cost, namely operating costs per train mile and percentage of operating costs affected by additional distance and curvature, were readily approximated. The final figures accepted by both parties were a compromise between the Erie's estimate of a gradual increase in traffic based on past experience on the entire Erie System, and the Commission's contention that the increase in motor transportation and the probable reduction in output at the Ringwood mines presaged no increase in traffic on this portion of the system.

The construction of a new railroad line involves, for a few years, a maintenance cost in excess of the normal amount, on account of necessity of repairing settlement in heavy fills and taking care of other similar conditions. This is particularly applicable to high submerged embankments, such as the line crossing the reservoir. The Railroad was allowed an amount to compensate for this excess expenditure based on its experience under similar conditions elsewhere. The final allowances made by the Commission and by the Railroad Company, for the various elements affecting the cost of operation, were as follows:

Additional Costs (Allowed by Commission).

(1) Increase in distance and curvature (Annual cost capitalized at 5 per cent.)		$93 208
(2) Extraordinary maintenance (Total cost extending over 5 years.)	$72 150	
Less discount for payment at beginning of period	9 952	62 198
Total		$155 406

Reduced Costs (Allowed by Railroad Company).

(3) Decrease in rise and fall (Annual cost capitalized at 5 per cent.)	$16 570	
(4) Decreased maintenance and renewal of structures (Capitalized at 5 per cent.)	18 000	
(5) Elimination of grade crossings	5 000	39 570
Net amount payable to Erie Railroad Company		$115 836

Construction of Highways. The contract for the grading work for the highway relocation was in the regular unit-price form and was awarded to Jose Naples, Inc., Frank Naples & Son, Inc., and P. Naples & Co., Inc., of Passaic, on September 10, 1925. It consisted of 3.90 miles of relocation of Greenwood Lake Road, 1.25 miles of relocation of Ringwood Road, and 1.71 miles of relocation of West Brook Road.

The greater portion of this work was on a rugged hillside-location along the shore of the reservoir, and the usual steam-shovel methods were employed. All material from the excavation and for the fills was transported by trucks. Opening of borrow pits was necessary for many of the fills. The culverts were generally of pre-cast concrete-pipe up to 42 in. in diameter.

Greenwood Lake Highway was completed on June 25, 1927, Ringwood Road, on November 30, 1926 and the paving of West Brook Road on June 30, 1927. The county authorities paved the main highway with two courses, 3 in. thick, of bituminous concrete on a 7-in. stone base 24 ft. wide. This work was done from July, 1927, to May, 1928.

Construction of Railroad. The railroad was constructed on a unit-price basis by Winston & Company, Inc., of Kingston, New York, the lowest of fourteen bidders. Work was begun in July, 1925. The principal features were a deep rock-cut near the southerly end of the relocation and four heavy, riprapped fills each with a large concrete culvert. Borrow pits were opened within the reservoir, and the fills were started by truck haulage. However, a narrow-gage railroad line was ultimately built the whole length of the contract for haulage of earth and rock.

Timber trestles were built to carry the relocation over highways and railroad that were required to be kept open for traffic on the old locations during construction of the new. Fills were side-dumped from trestles. Four large arch culverts were required in the principal fills, one a double-

barrel, 15 x 19-ft. section, and the largest a triple-barrel culvert of the same section. Culverts less than 7 ft. in diameter were generally of pre-cast reinforced-concrete pipe.

The largest fill across the Ringwood Creek arm of the reservoir, amounting to 115 000 cu. yd., was completed in August, 1926. The next largest, over the main Wanaque River, near the upper end of the reservoir, had a volume of 98 000 cu. yd. and was finished in September, 1926.

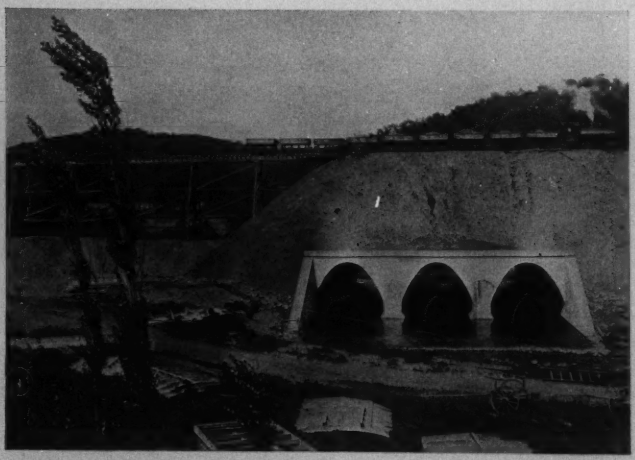

FIG. 22.— WANAQUE RIVER CULVERT FOR ERIE RAILROAD RELOCATION. September 15, 1926.

The deep rock-cut, about 1 000 ft. long and 65 ft. in maximum depth, was completed in July, 1927. The rock from this excavation was used to riprap railroad-embankments, the approaches to West Brook Viaduct and Midvale Dam. The railroad riprap was dumped from the top of the embankment, mostly when the ground was frozen. This method was generally successful in placing the material where required. The contract was finished in October, 1927.

Laying of track by Railroad Company labor began in June, 1927, and on October 31, 1927, the first train was run over the new track. The same track gang removed the rails from the abandoned line within the reservoir. Most of the ties were burned. This work was completed in the summer of 1928. In the winter of 1927–1928, the gaps in the new line, where it crossed the old, were filled. In the summer of 1928, a track gang was engaged during a large portion of its time, in keeping the new roadbed to grade. This work was at first paid for by the Commission but finally merged into regular maintenance by the Railroad Company.

Miscellaneous Structures.

West Brook Viaduct. This structure, of the deck girder and slab type, has five 75-ft. and two 65-ft. spans in an overall length of 505 ft. The bridge is supported upon six main piers varying in height from 45 ft. to 75 ft. Earth embankments extend about 200 ft. into the reservoir on each end surrounding the abutments. The foundations of the piers are on sand and gravel. Wooden piles, 3 ft. on centers, were driven to an average depth of 28 ft. for four of the piers.

Fig. 23.— West Brook Road Relocation.
Old road in left center of picture; new road with guard rail on right. Clearing of reservoir basin in progress, July 25, 1927. Timber and slash removed or burned before reservoir was filled.

The roadway is 16½ ft. wide, and a sidewalk 3½ ft. wide on the south side of the roadway accommodates pedestrians. If conditions at some future time require the change, the sidewalk may be removed, thereby providing a roadway width of 20 ft.

Each span is designed to be entirely independent, separated from adjoining spans by expansion joints, and supported at one end by a rocker bearing. This design was adopted because the whole structure is founded on earth and the possibility exists of slight settlement and deflection of piers. With independent spans, any slight movement would cause no additional stresses in the superstructure. The viaduct is designed for a uniform live-load of 100 lb. per sq. ft., or for a line of 15-ton trucks close together. The theoretical stresses due to these loads combined with dead loads and wind stresses will not exceed the allowable figures recommended

FIG. 24.— WEST BROOK VIADUCT.
South side as viewed from West Brook Road at west end of viaduct, April 2, 1928.

by the Committee on Reinforced Concrete of the American Society of Civil Engineers.

The piers and pier bases were designed as gravity structures of plain concrete with uniform foundation pressures of less than 2.5 tons per sq. ft. It was assumed that ice pressure equal to the crushing strength of ice might be exerted on the ends of the piers. For that reason, these ends were pointed throughout the upper 25 ft. The piers, as designed, will withstand an ice thrust of 135 tons each at El. 300, acting lengthwise of the pier, and a brake load of 15 tons each, acting lengthwise of the bridge. Under these momentary conditions, higher stresses will occur in the piers and foundations. The design of the structure was reviewed by R. C. Falconer, Consulting Engineer.

Construction work began in August, 1926. The approach fills were made by truck haulage. The concrete-mixing plant was located south of the viaduct near the easterly edge of the river, opposite the fifth span from the west end. Concrete was raised to the elevation of the viaduct in a 90-ft. tower and distributed into the pier forms either direct by chutes or bottom-dump buckets handled by a traveling derrick. This ran on a temporary trestle long the north side of the viaduct. The piers were poured first. The deck falsework was then erected. This consisted of 8 x 10-in. vertical members on pile foundations, supporting a solid platform at the elevation of the bottom of the girders. Upon this platform the girder- and slab-forms were erected. The falsework for the entire structure was built completely. No attempt was made to use any timber a second time.

Each span, including girders, slab and curb, was poured in a continuous operation. Concrete for the deck was dumped from the tower skip into a hopper from which it was distributed by hand buggies operating upon a temporary platform, the full length of each girder. The pouring of a bay at first consumed 16 hours, but was later reduced to 10½ hours. Railings for each span were poured in one continuous operation with no joints.

A waterproofing of three coats of hot asphalt and a two-ply membrane was applied to the deck before placing the pavement. The paving was asphalt block on ½-in. sand-grout cushion. The viaduct was opened to traffic on January 7, 1928.

Clearing and Grubbing. This contract was let to the Clifford F. MacEvoy Company on April 7, 1927, on the basis of payment for the number of trees cut in various classes; 2 to 12 in., 12 to 24 in., and over 24 in. in diameter. This form of contract made necessary the counting of trees previous to beginning the cutting operations. In general, the upper limit of grubbing was El. 305 and the lower limit, El. 280. Trees were chopped down within 2 or 3 ft. of the ground, and stumps were blasted out. Grubbing was done by hand. A large proportion of the trees were cut into cord wood and hauled out of the reservoir. In inaccessible locations, they were

burned along with the slash and stumps. The lower areas of the reservoir were cleaned first, so that filling would not be delayed. Excretal material in the vicinity of former dwellings was excavated and burned. The work was completed in May, 1928.

Midvale Dam. This is a structure on the east side of the reservoir about 900 ft. long with a concrete core-wall and earth banks. The maximum

FIG. 25.— CLEARING WANAQUE RESERVOIR.
August 3, 1927.

height is about 40 ft. A contract on the unit-price basis was awarded in May, 1927, to Winston and Company, Inc.

Work was begun on May 17, 1927. The concrete for the core-wall was mixed in a portable pavement-type mixer adjacent to the wall. Wooden forms were used. Selected embankment was excavated by steam shovel from an area 500 ft. west of the dam and hauled in trucks to be spread and rolled in the usual manner. General embankment was hauled by trucks from a borrow pit within the reservoir. The material was gravel, and no special compacting methods were used, other than placing the fill in layers about 12 in. thick. Riprap was placed in advance along the toe of the dam as it was excavated from the railroad cut previously described. It was transferred up the embankment by shovels as the banking progressed. The upper part of the riprap was dumped from the top after the completion of the earthwork. Top-soil for the downstream slope was delivered to the top of the dam and scraped downward along the slope by a cable-operated scraper. This work was completed in April, 1928.

Wire Fence. About 13.6 miles of 5-ft. and 7-ft. wire fence were erected along the highways, across some of the dams, and along the boundary of part of the reservoir lands. In general, the entire southerly and easterly boundaries of the reservoir lands were fenced. The westerly side was not so protected, as this area is at present quite sparsely inhabited. The contract was awarded to the Atlas Fence Company of Newark, N. J., and work began in October, 1927. Wooden posts were used where the fence served as a combined highway guard. Elsewhere the posts were steel angles set in concrete. The contract was completed in September, 1928.

Reforestation. About 360 000 two-year seedlings of white pine and arbor vitae, and three- and four-year transplants of red pine, Scotch pine, Norway spruce, hemlock and mountain ash were set out in rows about 6 ft. apart in the spring of 1928 in cleared areas around the reservoir.

Minor Structures. A number of other works were constructed in connection with the Wanaque Reservoir, but they are unimportant compared with those described. These structures may be listed as follows: Post Brook diversion-works, overflow-channel dams, Furnace Road Dam, Wanaque Tunnel, Ringwood Mines Pumping Station, removal of oil pipeline and removal of cemeteries.

Sanitary Precautions Taken. Throughout the life of all the contracts, stress was laid upon sanitary and medical precautions to protect the health of employees, the local communities, and the people using water from the drainage areas affected by operations. The contamination of water supplies was guarded against, and adequate sewage-disposal works were constructed for the group of buildings east of the dam. Within the reservoir, the tight-can type of sanitary convenience was required. All garbage was buried on Commission property outside the watershed.

Real Estate. The flooded lands in the reservoir cover an area of 2 400 acres. An additional strip for sanitary protection was acquired, about 1 000 ft. wide around the reservoir. The total area, including extra lands for railroad and highways, amounted to about 6 000 acres, divided into 157 separate parcels. Acquirement was by purchase when prices, considered reasonable by the Commission, could be obtained. When not, condemnation was resorted to under the law of eminent domain.

The most important land acquisition was the property of the Ringwood Company and Miss Sarah C. Hewitt. This consisted of 15 parcels within the reservoir containing 2 356 acres and 3 parcels containing 355 acres. Negotiations with the so-called "Hewitt interests," owning more than half of the land required for the Wanaque Reservoir, extended over a number of years, but no agreement could be reached. Finally, in 1925, a petition was filed asking for the appointment of condemnation commissioners to determine the amount which the North Jersey District Water Supply Commission should pay for the Ringwood properties.

Hearings on the Ringwood Company case before three condemnation commissioners continued for 29 days until May 13, 1926. The owners pre-

sented expert testimony in regard to land values and claimed power values, real-estate lake developments, values for sand and gravel deposits, and special value for water-supply purposes, stating that a water project similar to the Wanaque development could be built on the Company lands and water sold to cities in the Metropolitan area.

On July 1, 1926, the condemnation commissioners made an award for the Ringwood Company land of $1 809 418, including certain stipulated interest. This award was greatly in excess of the values as appraised by the real-estate experts of the Water Commission. Appeal from the award was, therefore, taken, the case being tried before a jury in the Circuit Court of Passaic County. The jury on February 4, 1927, reduced the award to $654 641, plus interest amounting to $56 711.

The award of the jury was appealed by the owners to the Court of Errors and Appeals on July 30, 1927. The principal grounds for appeal were stated to be as follows:

> The jury was compelled to determine the value . . . for water-supply purposes without having heard . . . testimony concerning its market value for that purpose. The jury was deprived of hearing testimony concerning the value of the property by reason of its containing beds of sand and gravel.

It was also alleged that a "misapplication of the rules . . . was made by the trial judge." On October 15, 1928, the Court of Errors and Appeals affirmed the verdict of the Circuit Court. The Ringwood Company then made application for a re-argument to the Court of Errors and Appeals. This application was denied, and the same Court refused to grant a certificate that a Federal question was involved, so that the landowners were unable to carry the case to the United States Courts. The Company accepted the amount of the jury award, and the litigation was ended.

Aqueduct.

The State Water Supply Commission's Wanaque Project, adopted by the North Jersey District Water Supply Commission for its first project, provided for a 72-in. steel pipe from the reservoir to Paterson, a 60-in. steel pipe from Paterson around Watchung Mountain to Newark, and a 36-in. steel pipe from Newark to Kearny. The $9 047 250 project of 1918 provided for the same size of pipe line from the reservoir to Newark.

In the subsequent contract, the aqueduct was to have had a capacity of 140 m.g.d. with a diameter of 105 in. for a mile from the reservoir, followed to the Paterson connection by a capacity of 70 m.g.d. and a diameter of 90 in., and to Belleville by a capacity of 60 m.g.d. with a diameter of 84 in.

Early in 1924, when the participation of cities other than Newark began to show more definitely what the demands on the aqueduct would be, it became apparent that the aqueduct sizes proposed would be inadequate

even when first put into service. Consequently it was decided to fix the Wanaque aqueduct-capacity at 150 per cent. of the average draft.

In the supplemental contract of January 24, 1924, subsequently participated in by the eight municipalities, the aqueduct capacities were fixed as follows:

Wanaque Reservoir to Paterson connection	150 m.g.d.
Paterson connection to Bloomfield connection	105 m.g.d.
Bloomfield connection to Belleville connection	97 m.g.d.

Great Notch Tunnel. Previous to the actual adoption of the aqueduct projects of 1924, a study of a tunnel through Watchung Mountain, instead of a pipe line around it through Paterson, had developed sufficient advantages to warrant adoption. The larger needs were so well assured that, with the concurrence of the city of Newark, construction of this stretch of aqueduct was begun in November, 1922, under a contract with the Heyman and Goodman Co. of Jersey City on the unit-price basis. The tunnel is about 9 000 ft. long in trap rock and red sandstone, the two characteristic formations of Watchung Mountain and the territory in its vicinity.

The tunnel was driven from the two portals through 3 267 ft. of trap rock from the north end, and through 6 105 ft. of sandstone and shale formation from the south end. Timber support was necessary in the sandstone, but the trap rock generally required no roof support. The trap rock was hard and dense, and little water was encountered. The sandstone, however, developed a total inflow amounting at one time to some 1 400 g.p.m.

The headings holed through 5 175 ft. from the south portal on February 17, 1925. Driving from the north portal had previously been suspended and trimming completed, so that in June, 1924, invert concreting was started from the north end. The mucking track was raised above the section of the invert to be concreted, and concrete was delivered over this "high line." After the concrete had set, the track was lowered upon the finished invert, and the "high-line" equipment was moved forward, the process of concreting being continued. Longitudinal strips, forming a radial joint between invert and arch, and steel screeding plates, cut to the radius of the finished invert, served as forms for the concrete. This was rolled to a finished grade by a 4-in. pipe roller, 12 ft. long, resting on the screed plates and worked from side to side by the men's feet. The surface was finished with a trowel. The size of the drain depended upon the amount of water encountered in stretches of 300 to 400 ft. Generally 4- and 6-in. pipe, laid loosely and covered with sheet steel, was used. The small size of the tunnel, and the necessity of maintaining pump lines to deliver the water to the portal, made invert concreting difficult.

In October, 1924, the invert in the north end being completed, arch concreting was begun. A 60-ft. Blaw-Knox steel form was used. This was

mounted on a carriage which traveled on the 2-ft. gage track laid on the invert. A Webb-Cox pneumatic concrete gun, served by four 1-cu. yd. car trains, hauled by storage-battery locomotives from the mixer, was used to place concrete. The mixing and crushing plant was located about 200 ft. from the north portal. All coarse aggregate used in the tunnel was obtained by crushing and screening the trap rock excavated from the north portal. Sand was purchased from a local sand pit.

FIG. 26.— GREAT NOTCH TUNNEL NEAR SOUTH PORTAL.
Timbered section in red sandstone rock, August 13, 1923. Very wet excavation shown by flow of water in bottom.

In concreting the tunnel arch, the water was handled by "panning" or "piping-through." All the tunnel in sandstone and 1 600 ft. of that in trap were provided with an invert drain of 4-in., 6-in or double 6-in. light steel-pipe, depending upon the amount of water. This drain was broken for sumps at intervals of some 400 ft. Grout pipes 2 in. in diameter, connecting into the drain, were spaced approximately 40 ft. apart along the invert drains. At higher points in the arch lining, other pipes were placed for purpose of grouting, or for venting the air when grout was injected into the neighboring holes. Provision was made for passing these pipes through the steel forms by installing, in advance, threaded openings 1½ in. in diameter in the steel plates of the concrete forms. These could either be closed by plugs or connected by means of a nipple with such pipes. There were 650 of these grout pipes, and 80 000 sq. ft. of steel "panning" were required in the tunnel. The inflow of water was, in general, distributed over three principal zones. The inflow between these points was largely

confined to the bottom of the tunnel and was handled by the invert drain and weep holes. In the three zones mentioned, however, there was some seepage of water through the concrete lining, even with extensive "panning" and with many weep holes provided in the side walls and arch.

The grout plant consisted of two Cuniffe grout machines, mounted side by side on a special platform truck. These were connected to a single 1½-in. hose, which was connected up successively to the various grout pipes. Compressed air was furnished from the north-portal air-compressor plant. The water for the mix was obtained by gravity flow through a similar 4-in. line leading from a brook at the south portal. Grouting was begun at the north portal and, as it progressed southerly, this water line was broken at the machine for each move. The part disconnected was used to extend the air line. Sand and cement were pushed into the tunnel on flat cars by an electric storage-battery locomotive and transferred to storage cars trailing the grout machines.

Grouting was started about 600 ft. in from the north portal on December 7, 1925, and was carried on continuously with three shifts per day, Sundays excepted, until February 15, 1926, when the south portal was reached. The machines were then taken back to grout the remaining 600 ft. to the north portal. The procedure in grouting was to place valves on all grout pipes within a reasonable distance of the starting pipe, and, as grout showed at these pipes, to close the valves. Grouting was continued to refusal. Connection was made to every pipe not showing grout from a previously-grouted pipe. Valves were left in place for two days after the pipes were grouted. They were then opened and removed. In a few cases in which the pipes still leaked, they were grouted a second time.

The mix used throughout the work was one bag of cement to one bag (95 lb.) of fine, bituminous sand and 7 gal. of water, producing a liquid volume of 2.2 cu. ft. of grout. An air pressure of 100 lb. per sq. in. was used in the trap-rock portion and of 50 lb. per sq. in. in the sandstone portion.

In the trap, grout did not travel much farther than one or two pipes, and it seemed that each 60-ft. section of concrete lining formed a concrete cut-off at its ends past which grout could not flow. In the sandstone, grout often appeared 300 ft. from the pipe being grouted, even when a pressure of 50 lb. per sq. in. was employed.

A grouting crew usually consisted of one foreman, one operator, one dinky driver and six laborers. Under average conditions, 300 batches were placed in an 8-hour shift, the maximum being 427. After the first or preliminary grouting had been completed, it was found that there were still about 150 g.p.m. of seepage into the tunnel. Since about a foot of muck, made up of rock trimmings, spilled concrete and grout, covered the invert, the location of the leakage had to remain undetermined until the clean-up. As cleaning of the tunnel invert progressed, the leaks uncovered were grouted. In consequence, the leakage, as measured by a weir installed at the south portal, was finally reduced to only 20 g.p.m. In the grouting,

35 372 bags of cement were used. In trap rock an average of one bag per foot was employed, while in the sandstone about 5 bags per foot were placed. A total of 2 902 cu. yd. of grout was used in the entire tunnel.

While the tunnel was built on the hydraulic gradient, it was grouted to be tight against external pressure, principally as a sanitary protection against drainage from cemeteries located on the surface above. This feature made the tunnel adaptable to the new higher gradient when the all-pressure line was subsequently adopted.

Aqueduct Hydraulics. As previously stated, the 50-m.g.d. Wanaque project provided mainly for an adqueduct of 72-in. steel pipe which was planned to be laid mainly in public roads. When the project was increased to 100 m.g.d., and it was decided to provide 150 per cent. aqueduct capacity on account of a number of the participants having no local storage, the economies of a grade aqueduct were given consideration. The maximum size of conduit for such a capacity would be about 9 or 10 ft. in diameter. It was also decided to provide for aëration, and the best location for aërators was deemed to be at the foot of Raymond Dam, appurtenant to the aqueduct headworks.

The elevation of the aërator basin was placed at the drawdown elevation of the reservoir (El. 240), using the head in storage for aëration. A hydraulic gradient sloping about 2 ft. to the mile from the aërator basin to Newark gave an elevation of delivery at Newark's Belleville reservoir of 197. This was sufficient for the low distribution-area of Newark and for the cities of Bayonne and Elizabeth which are on the seaboard. Such a gradient provided gravity service to the vicinity of the areas mentioned even with Wanaque Reservoir drawn down, but pumping was required for the higher areas. This gradient, also permitted construction of grade aqueduct over about half the distance for the larger-capacity aqueduct; about 6.4 miles of the upper 13 miles of aqueduct.

Great Notch Tunnel and about 5 000 ft. of approaches had been built on this hydraulic gradient, and a terrace at El. 240 had been constructed at Raymond Dam for the aërator, when some questions were raised in regard to the advisability of separate pumping by municipalities, aëration, elevation of delivery at the lower end of the aqueduct, costs of rights-of-way for a grade aqueduct and collateral matters.

George A. Johnson, consulting engineer of New York, was accordingly engaged to advise on the design of the aqueduct and subjects relating thereto. On March 29, 1927, he recommended the adoption of twin pressure-lines of 72-in. "smooth-bore" steel pipe and the elimination of aëration. Subsequently F. Herbert Snow, consulting engineer of Harrisburg, Pa., reviewed the matter and concurred in the main with Mr. Johnson's recommendations. Mr. Snow recommended that 74-in. smooth-bore steel pipe be installed instead of 72-in., that the full head of the Wanaque Reservoir be made available in the aqueduct, that aëration was not necessary for Wanaque water, and that Great Notch Reservoir of the Passaic Consoli-

dated Water Co. at El. 425 be incorporated in the Wanaque project to act as an equalizer upon the entire transportation system and to make use of water otherwise wasted over Wanaque Dam, since the grade-aqueduct could only carry a maximum of 150 m.g.d.

The twin steel-pipe line was adopted, but the matter of aëration and pressures was later referred by some of the municipalities to Fuller and

FIG. 27.— WANAQUE AQUEDUCT.
Typical view of 74-in. twin pipe line.
April 24, 1929.

McClintock, consulting engineers of New York, who reported to the city of Paterson, under date of April 16, 1928, recommending that the full head of the reservoir be made available for the aqueduct and that aëration be provided. In order that a head on the aqueduct equal to at least El. 280 might be available when the aërator was in operation and also when the flow-line of the reservoir was below that elevation, the installation of a pumping station at Wanaque was advised.

The recommendations of Fuller and McClintock were adopted, and in September, 1928, they were engaged to design and supervise the construction of the Wanaque Aqueduct. Under their direction the following construction work has been in progress:

Wanaque Aqueduct: Thirteen miles of twin line and 5 miles of single line, 74-in. lock-bar steel pipe. T. A. Gillespie Co., contractor. Work completed.

Wanaque Headworks: Pumping-station building; service building, gatehouses, aërator, connecting piping and landscape work at Raymond Dam. Sumner Sollitt Co., Chicago, Ill., contractor.

Status of work: masonry work for pumping station completed and piping laid; masonry work for service building, 95 per cent. complete;

masonry work for control house and lower gatehouse begun and concrete work in aërator complete except for floor.

Pumping Equipment: Five 23-m.g.d. and one 11-m.g.d. centrifugal pumps to operate against a head of 65 ft.; two water-turbine-driven centrifugal pumps, 100 g.p.m. against a 250-ft. head and 125 g.p.m. against a 175-ft. head, and one electrically-driven centrifugal pump, 100 g.p.m. against a 250-ft. head. Turbine Equipment Co., contractor.

Status of work: Turbine pumps in lower gatehouse delivered and connected; pumps for pumping station completed and ready for shipment.

Electrical Equipment: Five 400-h.p. and one 200-h.p. synchronous motors with transformers, circuit breakers and other equipment. Watson-Flagg Engineering Co., Paterson, N. J., contractor.

Status of work: Seventy-five per cent. of equipment in substation court installed and cells in the circuit breaker room poured. Motors for pumps completed and in hands of pump contractor for shipment.

Reinforcement of Wanaque Tunnel: Laying 1 485 ft. of pre-cast concrete pipe within the previously-built tunnel. Lock Joint Pipe Co., contractor. Work completed.

Balancing Reservoir: Covered concrete reservoir, 15 million gal. capacity, adjacent to aqueduct in Clifton. Munroe and Westcott, Inc., North Attleboro, Mass., contractor. Work 90 per cent. completed and back-filling in progress.

Steel Pipe, Contract 25. The steel-pipe contract provided for alternative proposals for approximately 164 000 linear ft. of pipe, the portion of the aqueduct from Wanaque Tunnel to Great Notch Tunnel to be constructed as a twin line and the portion between Great Notch Tunnel and Belleville Reservoir as a single line, the minimum pipe-diameter to be of 74 in. with differentials in diameter for various types of pipe, the minimum thickness of plate for all types of pipe to be $\frac{7}{16}$ in. Bids were permitted for 74-in. lock-bar pipe, 74-in. hammer-welded pipe, 74-in. countersunk-riveted pipe in 30-ft. courses, 75-in. button-head riveted pipe in 30-ft. courses, 74-in. countersunk-riveted pipe in $7\frac{1}{2}$ ft. courses with butt girth joints, 76-in. countersunk-riveted pipe in $7\frac{1}{2}$ ft. courses, and 78-in. button-head riveted pipe in $7\frac{1}{2}$-ft. courses. The pipe was to be laid in a trench with 3 ft. of cover. The twin line was to be provided with 6 cross-connections to permit cutting out a section for cleaning or repairs.

The lowest bid was for lock-bar pipe. The pipe is dip-coated with "Ovarco" pipe-coating and is protected on the exterior by a wrapping with "Pabco Soil Proof Wrap."

The contract was awarded on December 20, 1928, and the time of completion was fixed at 21 months after date of service of notice on the contractor to begin work. The contract was subject to three provisions for completion of parts of the work at various stages so as to permit delivery of water at certain points along the line of the aqueduct, if needed. The third provision required that within 18 months after service of notice to begin work, all pipe lines and appurtenant work be so completed as to permit satisfactory and continuous delivery of Wanaque water to the municipalities in full quantities. The contract was extended to include the

connections of the steel pipe into either end of Great Notch Tunnel. Lock Joint concrete pipe was used for this purpose at the two tunnel portals. The tunnel was also regrouted under the same contract, making a complete aqueduct job from Wanaque to Belleville.

The contractor made remarkable progress and, when in the fall of 1929 the city of Bayonne indicated a willingness to contract with the Commis-

FIG. 28.— WANAQUE AQUEDUCT.
Typical view completed 74-in. twin pipe line
before back-filling May 9, 1929.

sion and municipalities for surplus Wanaque water on a basis of delivery in early 1930, the contractor for the pipe line agreed to expedite the work on the basis of a bonus of $2 000 per day. The pipe line was sufficiently completed to permit delivery of water to Bayonne on March 11, 1930. The final work on the aqueduct was finished in July.

Headworks. The headworks at Raymond Dam consist of the aërator, pumping station, lower gatehouse, control house and surge tank. The water drawn from the upper gatechamber through the two 72-in. steel pipes previously described passes up through two 48-in. pipes either to the control house and thence to the aërator or pumping station, or it may be by-passed directly into the upper end of the aqueduct. The aërator effluent goes through two 60-in. steel pipes to the pumping station. There it will be pumped by electrically-operated centrifugal pumps, discharging into the aqueduct through five 36-in. and one 24-in. steel pipes. Direct connection through a 60-in. steel pipe is also provided from the lower gatehouse to the pumping station. A surge tank of 1 190 000 gal. capacity with an overflow level at El. 300 is located at the south end of the dam.

The aërator is provided with 165 nozzles of the vane type, reducing

from 5-in. to 2½-in. discharge. A number will be provided with a cap having a 1⅜-in. orifice for smaller discharges. The nozzles are arranged in three large and three small symmetrical groups with four controls. The aërator basin is 234 ft. by 82 ft. in plan. It is built of concrete, faced with stone on the exposed surfaces and slate on the bottom and with a granite curb and paving blocks around the outer periphery.

FIG. 29.— CROSS-CONNECTION CHAMBER, WANAQUE AQUEDUCT.
April 24, 1929.

The pumping station is a building 120 ft. by 45 ft. in plan and will contain five 30-in. pumps with 400-h.p. motors, one 20-in. pump with 200-h.p. motor and the usual transformers and other electrical equipment. Current will be purchased from the Jersey Central Power & Light Company.

A service building 96 ft. by 47 ft. in plan is located symmetrically with the pumping station and will provide office, laboratory and garage space for the operating forces. It will also contain public toilets.

The gatehouse, pumping station and service building have been built of Delaware River stone.

The firm of Charles Wellford Leavitt and Son has been engaged to supervise the final landscaping in harmony with the original Leavitt conception.

Final Estimate. The final changes in aqueduct and headworks together with adjustments to meet unexpected land and other costs required a modification in the estimated cost of the project.

The final supplementary contracts, executed in 1928, were based on an estimated cost of $26 542 000. The actual cost of the Wanaque Project to June 30, 1930, has been $24 349 308. A summary of the completed quantities of principal items of major contracts is given in Table 2.

TABLE 2. — COMPLETED QUANTITIES OF PRINCIPAL ITEMS OF MAJOR CONTRACTS.

Contract.	Earth Excavation. Cu. Yd.	Rock Excavation. Cu. Yd.	Refill and Embankment, General. Cu. Yd.	Refill and Embankment, Compacted. Cu. Yd.	Concrete. Cu. Yd.	Borrow. Cu. Yd.	Riprap. Cu. Yd.
Contract 2A							
Portions of Raymond Dam	86 552	4 623	114 494	40 661	5 731	.....	.....
Contract 3							
Great Notch Tunnel and Approaches	10 579	36 644	20 957	.....	20 312	.....	.....
Contract 7							
Raymond Dam and Appurtenances	62 231	24 078	710 377	214 712	77 437	.....	80 932
Contract 8							
Relocation of Erie Railroad	98 029	112 692	.....	.....	8 972	531 125	55 379
Contract 9							
Relocation of Highways	124 771	49 540	.....	.....	2 197	113 477	5 118
Contract 11							
West Brook Viaduct	4 276	.....	33 241	.....	3 709	.....	4 322
Contract 18							
Midvale and Furnace Road Dams	1 461	130	93 215	14 184	5 098	.....	11 656
*Contract 25**							
Wanaque Aqueduct	447 188	26 710	456 510	41 700	27 100	147 650	.....
Contract 29							
Reinforcement of Wanaque Tunnel and Approaches	1 768	482	.....	150	290	.....	.....
*Contract 33A**							
Wanaque Headworks	19 295	6 145	12 225	1 295	1 706	.....	.....
*Contract 35**							
Balancing Reservoir	19 400	2 570	.....	.....	4 564	.....	.....
Total	875 550	263 614	1 441 019	312 702	157 116	792 252	157 407

*Quantities as of June 30. 1930.

Operation.

The Wanaque Reservoir was filled on March 4, 1929. The summer of 1929 was extremely dry, and the flow of the Passaic River was very low. Coupled with this, the industrial consumption in the city of Paterson reached an unprecedented amount in August of that year. Happily the water stored in Wanaque Reservoir was available, and the first users of Wanaque water were the cities of Paterson, Passaic and Clifton and other customers of the Passaic Consolidated Water Company. A volume of 3 325 million gal. of water was let out of the Wanaque Reservoir during the year to run down the river to supplement the supply at the Little Falls filtration plant of the Passaic Consolidated Water Company.

The aqueduct was completed and delivery of water begun through the pipe line on March 8, 1930. The first municipalities to receive water were Kearny, one of the participants, and Bayonne under a purchase agreement with the participants. This water was delivered through a 48-in. pipe line constructed by the town of Kearny from Belleville, the terminus of the Wanaque Aqueduct, across the Passaic River to Kearny where, by means of a 42-in. connection, it connects with the Bayonne pipe line as well as serving Kearny itself.

The delivery of water at this writing (September 1, 1930) is:

Newark	17.5 m.g.d.
Kearny	3.1 m.g.d.
Montclair	3.5 m.g.d.
Bayonne	11.6 m.g.d.
Total	35.7 m.g.d.

The city of Newark has recently constructed a 60-in. steel line from Belleville to Elizabeth. Both cities have coöperated in financing the line, and Wanaque water will shortly be delivered to Elizabeth by an arrangement with the Elizabethtown Water Company, now supplying that municipality. The city of Elizabeth proposes to acquire the distribution system from the water company. The new pipe line also serves as a major transmission main to the large industrial area of Newark.

The town of Montclair is at too high an elevation to be served by the Wanaque pressure. A pumping station has, therefore, been built in the northerly end of the town adjacent to the Wanaque aqueduct. Montclair has entered into an agreement to pump Wanaque water at this station for Glen Ridge and will probably also pump for other municipalities lying above the Wanaque hydraulic gradient.

The cities of Paterson, Passaic and Clifton are not yet connected with the Wanaque aqueduct for the reason that they do not (with the exception of a part only of Clifton) own their distribution systems. The acquisition of the property of the Passaic Consolidated Water Company by these cities has been under way for a long time. A settlement has been agreed upon, subsequent to an award by a condemnation commission. The actual title

will be transferred in November, 1930. As soon as this is accomplished a preliminary connection will immediately be made at Little Falls. This will provide for the delivery of Wanaque water to the existing pumping station. The present consumption of the three cities, together with other existing customers of the Passaic Consolidated Water Company that the cities will take over with the property, is greater than the Wanaque allotment. For a time it will be necessary, therefore, to supplement the Wanaque supply for these communities with filtered Passaic River water.

It is proposed ultimately to separate the greater proportion of the industrial consumers and deliver Passaic water for those users, thus permitting the delivery of Wanaque water to the domestic consumers. This separation involves extensive changes at the Little Falls plant and pipe constructions within the cities. The necessary work will undoubtedly be under way in a few months.

Bloomfield is now laying a 16-in. cast-iron main which shortly will connect with the Wanaque Aqueduct.

Within a few weeks' time then, all the participants in the Wanaque Project will be receiving water from that system. Thus is completed the first District water supply system to be constructed in New Jersey.

Personnel. The Commissioners of the North Jersey District Water Supply Commission are: Frank H. Sommer, Chairman; Berkeley W. Moore, Jr., Charles Wagner, Douglas G. Thomson and Chrystal Brown. Morris R. Sherrerd has been Consulting Engineer on the project from its inception under the State Water Supply Commission to date. Robert Spurr Weston has been Consulting Sanitary Engineer. Neil C. Holdredge, Assistant Chief Engineer, has been in direct charge of all construction work. Arthur L. Sherman was Designing Engineer. Fuller and McClintock have been in charge of the aqueduct. Their representatives on the work have been Frederick C. Cunningham, Donald W. Howes and Allen A. Jones. The writer was Chief Engineer until June, 1929.

WATER SUPPLY AND DAMS IN JAPAN.

BY ALLEN HAZEN.*†

[*Read February 12, 1930.*]

After the World Engineering Congress in Japan last November there was an opportunity to see a few representative water works and dams. The inspections were too few and too rapid, because the local committees had planned so many delightful excursions and social functions which limited the available time.

The water-works engineers were most cordial and organized parties to visit their works, and some of their parties were attended by many of our American and a few other delegates.

It may be mentioned at the outset that George A. Johnson, after personal inspection, wrote a short description of some of the Japanese Water Works that may be found in the *Engineering-Record* of May 11, 1907, and also in the Proceedings of the American Water Works Association for that year, p. 252.

Japan has a large population on a small area, and the land is under a high state of cultivation. One would naturally expect that there would be great difficulties in securing enough good water for the large cities, of which there are quite a number.

The actual conditions, however, are rather favorable for the water-works business. The central part of the main island is mountainous and has but little population and produces water of excellent quality and abundant quantity, which is largely used for irrigation and for producing electricity, but so much as is needed is available for water supply.

The larger cities of Japan are grouped around this mountainous area, and none of them are very far from it. The aqueducts to Tokyo and Yokohama are only some 25 or 30 miles long. Because of this natural condition the problem of water supply is surprisingly easy. Some of the mountains and much of the soil of the foothills and plains is of volcanic origin, but the high mountains from which water supplies are drawn seem to be mainly of granite and other hard primitive rocks that yield soft waters entirely free from color and usually free from turbidity.

Yield of Catchment Areas. One of the most astonishing things is the large amount of water that is available. The catchment area of the Tama River above the Tokyo intake measures less than 200 sq. miles, but the river is astonishingly large in appearance and suffices to meet the needs of a population of more than two million people, using something like 50 gal. of water per capita daily. Until recently the supply has been maintained without storage. Now there is a limited amount of storage and this is being

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†Mr. Hazen died on July 26, 1930.

increased, but the flow of the stream is ordinarily sufficient to maintain service without storage.

I could not believe when I saw the river and the water being taken from it that the catchment area was as little as 200 sq. miles. But measurement of the excellent government maps confirms the accuracy of the figure that was stated.

Rainfall in Japan is much higher than it is in New England, and the conditions in the mountains are favorable to a large percentage of run-off. Rainfall is more abundant in summer than in winter, and this tends to offset the effect of summer evaporation and to produce flows that are more evenly distributed throughout the months of the year. This all tends to the possibility of maintaining maximum output with little storage.

If we take the conditions in New England as a starting point where in a general way the run-off is half the rainfall, and if, to make things more as they are in Japan, we assume that the rainfall is doubled while evaporation remains the same, the run-off will be increased threefold. Actually with a greater rainfall and wetter climate there will be less evaporation, and the actual run-off will be more than three times, possibly three and a half times, as much as it is in New England. This is not given as statistics, but to give a notion that will help in understanding Japanese conditions.

Perhaps this large run-off has something to do with the lack of color in the river waters, or there may be some other unknown explanation. At any rate, I did not see or hear of any water that showed an appreciable amount of color. It is obvious that with greater rainfall and run-off any tendency to color that there might be would be reduced by dilution. In addition we were told that the upper mountains were very bleak and wild and not covered by heavy forest and it may be that the color-producing conditions are less than they are with us.

The mountainous areas are very steep and rugged and almost uninhabited, but the foothills are inhabited and the ground toward the mountains is cultivated until the slopes become too steep. The water works of Tokyo and Yokohama have intakes, at elevations of something like 400 or 500 ft., high enough for water-works purposes. They have not been carried above all the inhabited areas, and there is more or less village and rural population on the catchment areas above the intakes.

Sanitation of Catchment Areas. The sanitary significance of this population may be less than it would be with us because of the Japanese habit of saving all human excrement and carrying it away to be used as fertilizer. Some of this fertilizer is no doubt used on cultivated ground within the catchment area, but it is all buried carefully in the soil in millions of places, a few ounces in each place in the hills of wheat and other crops as they are planted under conditions as favorable as may be for protecting the quality of the water. This use of human excrement no doubt tends to minimize the risk of pollution of the water. If any of it gets to the streams there are a number of conditions that tend to remove it.

There are first, the detention basins of considerable size through which the water passes on its way to the filters. Then there are the sand filters of high efficiency, and finally there is the chlorine apparatus standing guard, but not in use because the water leaving the filters is of such excellent test quality that the chlorine is not regarded as necessary.

Coagulant may also be used in treating the water when required, but it is not ordinarily necessary, and the water running in the streams as I saw it was brilliantly clear. Of course, this condition does not always obtain. There must be erosion and wash and turbid water at times. Great floods carry sand, gravel and boulders, as can be seen by the appearance of the river channels and the deltas which have been formed in their lower courses and extend into the sea.

Yokohama. Yokohama is supplied from a catchment area of 55 or 60 sq. miles south of the Tokyo area in the same mountains and no doubt having similar general character.

Kyoto. Kyoto is supplied by gravity from Lake Biwa, the largest lake in Japan, with a water surface of 267 sq. miles at an elevation of 285 ft. The catchment is some 1 400 sq. miles in area, some of which is most beautiful mountains, but the lake is surrounded with flat land carrying a heavy population.

A tunnel nearly two miles long has been cut through the rock rim of the lake to the valley in which Kyoto is situated only six or seven miles away and furnishes water which is used to develop power and for municipal water supply. The business, especially the electrical business, has grown in recent years so that a second tunnel has been added to increase the diversion.

Osaka. Osaka, the largest city in Japan, being slightly larger than Tokyo at the present time, is supplied with water pumped from a river not far from the city. The river is the outlet stream from Lake Biwa, but there are tributaries, and the Osaka intake is at a point below the junction of that branch on which the city of Kyoto is located. Kyoto is a city of some 700 000 inhabitants, and there is thus a potential source of pollution which may become greater in the future if the water-carriage system of sewerage is developed in Kyoto.

The water-works engineer of Osaka told me of his hope to be able to build a new water-works plant at no distant date, taking water from a higher point where it would be free from such potential pollution. By going far enough a gravity supply could be secured, but that does not seem to be contemplated at present.

Aome. I also had the pleasure of visiting the water works of Aome, a small city of 10 000 inhabitants, situated back in the hills within the Tokyo catchment, with pumping station, filters, covered service-reservoir and everything on a small scale that goes to make up a modern water-works plant. This included a modern Japanese residence for the superintendent adjoining the filters and a pure-water reservoir, where I experienced the charming hospitality of Mr. Nakajima and the members of his family.

Kobe. I learned that Kobe is supplied from impounding reservoirs but I did not have an opportunity of seeing them. All the other principal Japanese cities are said to be adequately supplied with water, all of good quality.

Springs. There are many springs, and no doubt spring water is used extensively for the smaller public and private supplies. Hot springs are especially numerous in Japan, and, in some cases, the hot water has been piped as a special service, much appreciated in the public and private baths; but with such small exceptions, so far as I heard, all the water used in Japan is surface water, and it is all filtered.

Filters. Both sand and mechanical filters are used, but sand filters greatly predominate. The water being clear and generally free from turbidity easily lends itself to the sand-filter treatment, and the results seem to be most satisfactory.

The sand filters have followed English rather than American models and remind one of the filters to be seen in London today and of those that were used in Germany long ago.

We were told that the Tokyo water works were originally laid out by a commission of engineers, of whom Burton who wrote the well-known English textbook on water supply was one member, and Gill, so long chief engineer of the Berlin water works, was another.

The devices used for handling sand are simple. There is no such labor-saving equipment as has been installed in the most recent American filters of this type. The dirty sand is carried out of the filters in baskets, two baskets being balanced over the shoulders of one man who walks up a runway and deposits the sand in a tramcar running on a track in the space between the filters. The tramcars carry the dirty sand to a central washer of the ejector type, something like those installed in early American filters at Albany and Washington. The clean sand is returned in the same manner.

The construction of the filters and all the structures connected with them is excellent. Granite trim is freely used on concrete work and adds to the durability of the structures and to their appearance after long years of exposure. The walls of the filters are made with frequent expansion joints so as to remain tight with changes in temperature, and perhaps also with small earthquake shocks.

The earthquake damage to the filters apparently has not been very heavy. In the earthquake of 1903, the heaviest in modern times, the filters at both Tokyo and Yokohama were not damaged to such an extent that they could not be repaired and ready for service as soon as the pipes in the city were ready to take the water.

At Yokohama, however, there was an older water-works plant in the lower city, which was completely destroyed. The masonry cover of the pure-water reservoir fell, and the filters were wrecked. This plant was abandoned and all the service transferred to the new plant situated in a better and higher location outside the city.

All the Japanese sand filters are open, and one of the practical problems is handling the algæ that grow in the water above the sand. This evidently is a matter of some importance at times, but does not prevent the satisfactory operation of the plants. Perhaps the large percentage of rainy and cloudy weather in Japan is not favorable to the production of heavy growths.

The rates of filtration originally were like those used in London and Berlin, but the traditional 100 mm. or 4 in. per hour has been increased moderately and the prevailing rate is now higher, up to perhaps double that first used. The rates, therefore, do not differ widely from the American rates of 5 or 6 m.g.d. per acre which are common for such filters.

At Kyoto there is the largest and most important filter plant on mechanical lines in Japan. This was built from plans by or following the ideas of the late Edmund B. Weston of Providence, R. I. It is a remarkable example of circular filter tubs with revolving rakes built in a most substantial way of concrete, in a beautiful building, with a great deal of granite trim. This plant treats the water from Lake Biwa. Coagulant is applied to water entering from the tunnel to a detention basin of about two hours' capacity, which is perhaps hardly enough for very soft water. It then passes to the filters and to a covered pure-water reservoir without aëration. There was some indication of red-water trouble.

In addition to the mechanical filters at Kyoto, two other plants of this type were seen, one under construction at Osaka, and one just completed but not yet in service at Yokohama. These were beautiful examples of concrete and masonry construction with very attractive buildings. They were both built to give additional capacity to meet increasing needs, the main supply in both cases being sand-filtered. On the other hand, for the new works of Kyoto, sand filters were being built for the extension.

In each of these three cases, the water-works engineers had turned to the other system from that previously used.

Most of the water supply in Tokyo and the other cities, except Osaka, is by gravity, but there are high-service districts where pumping is used. The water-works services are generally metered, and apparently metering will be universal in Japan as soon as that result is reached in America. Many of the water meters are made in Japan.

Consumption. I neglected to get exact data for consumption and other water-works statistics, but in a general way the average output at Tokyo and Osaka is about 100 m.g.d. each for some two million people, and at Yokohama and Kyoto the quantities are about one-third as great.

One must remember that the water-carriage system of sewerage is not generally used, and not much water is needed for flushing toilets. The Japanese are noted for their cleanliness and baths; but their habits of bathing differ from ours, and the per capita quantity of water required is undoubtedly less.

Innumerable silk mills and other industries must use great quantities of water, but these industrial supplies are no doubt drawn in most instances from streams of flowing water and not from the public water supplies.

One of the interesting things of the trip was that all my 150 American fellow-passengers wanted to know about the quality of water supplied in Japan before they landed. I had not been adequately advised in advance, but took the risk of saying that Japan was a civilized country and that I believed that the water would be found to be safe in the places where we should go, and at any rate that I was going to drink it until I could find out. My confidence in the Japanese water-works men was justified, and I had the pleasure before many days had passed of being able to assure my friends as to the quality of water in Tokyo and Yokohama and the other cities that we visited, and to tell them that it was quite up to the standards of quality in their own home towns.

Dams. A good many dams have been built in Japan, but most of them are rather recent. Both earth and gravity-masonry dams have been built. I was told that there was one small Ambursen dam in Japan but no arch dams of any description.

The earth dams are in what might be called the foothill region on earth foundation, built as dry fill with rolling. The materials are soil which is volcanic ash of extremely small grain size, but which packs dry to a hard reliable dam.

One of these dams, Ono Dam, about 120 ft. high, built by the Tokyo Electric Light Company, is a power dam and went through the earthquake of 1923. In location, about forty miles west of Tokyo, it was fairly near to the center of the earthquake disturbance and got the full force of the shock. It was full of water at the time and stood with some cracking and settlement. Afterward some additional fill was placed and the dam smoothed up.

Two similar dams, each a little less than 100 ft. high, have been built by the Tokyo Water Works, and a third and somewhat larger one is now being constructed. One of these dams had been built before the earthquake and the second was under construction. They settled and flattened a bit, but were not seriously injured.

All the other dams that I saw were farther back in the hills in rock gorges and rested on hard rock, either granite or some primitive rock approaching granite in hardness. One of these, the Kamaiki Dam, the highest in Japan, has a total height from foundation to top, of 290 ft., and will hold about 250 ft. of water. This dam was beautifully built with drainage gallery, drainage wells and all the other equipment of a substantial modern dam. No water had been stored behind it because there were legal questions that had to be settled first. The river was a navigable one, the navigation consisting in running logs from the mountains to the saw mills lower down. The electric company offered other facilities, but the logmen declined. It was hoped that this matter would be successfully terminated at an early date so that the dam could be filled. It is interesting to see that legal difficulties exist in Japan as in America.

Fashions in masonry dams run rather heavier in Japan than in America, and the ratio of thickness to height at any given points of the Kamaiki Dam

and other dams that we saw is about 0.85, as compared with the minimum of approximately 0.65, which has been used for many American dams.

In the case of one most interesting dam, this ratio was considerably increased. This was a dam something over 100 ft. high on the Ugigawa River, which is the outlet of Lake Biwa, and which flows down to and by Osaka. This dam, built for power purposes, is thicker than it is high and corresponds more or less in section and also in height with the Wachusett Dam.

The extra section was given in this case to avoid possible damage to Osaka in case of failure. This was done even though the quantity of water above the dam is not very great, and could hardly be embarrassing to Osaka in any event. However, the dam is a beautiful piece of work and the added masonry and cost were no doubt fully warranted by the peace of mind of the good people of Osaka who now have no occasion to worry as to the possible failure of this structure.

Most of the dams in Japan have been built for power purposes. The mountain valleys rise rapidly, and even a large dam usually holds only a moderate quantity of water. Storage to get seasonal equalization of flow is hardly possible. Such dams as we saw give complete control of daily flows and permit hourly peaks in power requirement to be met. That is as far as the storage will serve.

Japan is far advanced from an electrical standpoint. Of all the residences 85 per cent. have electric light and equipment, and this includes all the rural and agricultural population throughout the Empire. The use of electricity per capita is understood to be large and is increasing rapidly. The greater part of the electricity is produced by water power, and there are great undeveloped sources, so that building dams is likely to go on at a rapid rate in the next generation.

DIESEL ENGINE PUMPING EQUIPMENT: BOTH ECONOMICAL AND RELIABLE.

BY A. D. COUCH.*

[*Read September 18, 1929.*]

In this paper on the subject of economy and reliability of Diesel engines, the writer has purposely refrained from becoming immeshed in the technicalities of engine design. Considerations of this sort belong to the individual case in question and must be weighed by the buyer at the time of purchase. Experience with different types of engines has shown that peculiarities of design have very little to do with the operating statement at the end of the year. Therefore, the choice of a type of engine for a given situation should depend upon the special factors of that situation and upon the individual experience and judgment of the purchaser. At present there are on the American market many good makes of engines, all following the Diesel principle, but employing different methods to arrive at the same end. Probably the greatest contrast between methods is between the mechanical and the air injection of fuel. It would be enlightening if there could be discussions on the technical advantages and disadvantages of these two systems.

Historical. The first Diesel engine to pull a commercial load was built in 1898 by interests which now comprise the Busch-Sulzer Brothers, Diesel Engine Company.

This engine was placed in a brewery at St. Louis and is still located on the original foundation although it has not been operated for several years. The owners did not state the reason for its inactivity but perhaps the Eighteenth Amendment was a contributing factor.

Since the construction of this first Diesel, back in the experimental years of the industry, thousands of Diesel horse power have been put into service. Several years ago, the Busch-Sulzer Company made an investigation covering engines sold during a twenty-year period which showed that 96.7 per cent. were then in active service; 2.0 per cent. were for resale; 0.64 per cent. had been scrapped and 0.66 per cent. could not be located. These old engines were remarkably economical. A record is available of a fuel test of an engine built over twenty years ago which would pass muster today. In the case of a machine as near the practical limits in fuel economy as the Diesel, the buyer does not need to be greatly concerned about his purchase becoming out-moded in a few years.

In 1927, L. H. Morrison, a staff member of the magazine *Power*, made a survey of all full Diesel engines in use in the United States. He found that 290 686 h.p., or approximately one-fourth of all the Diesel h.p. then

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in use, was engaged in the pumping of water, sewage, and oil. This figure did not include the thousands of h.p. of semi-Diesel engines in use at that time. If this same proportion holds good today, approximately 750 000 h.p., of Diesel engines are now employed in some form of pumping in the United States alone. There are no figures available on the percentage operating in water works. However, it has been the writer's belief for some time that one of the best fields for Diesel engines is in the water-works business, and he feels confident that as time goes on, more and more of our plants will install this type of equipment.

In contrast to the 60-h.p. engine previously mentioned, is a 15 000-h.p. engine which, from all records available, is the largest Diesel engine in the world. It was built by Blohm and Voss of Hamburg, Germany, to M.A.N. patents and is now being operated in the municipal power station at Hamburg. It is a 9-cylinder, double-acting, 2-stroke cycle engine.

Efficiency and Cost. Probably we are all more or less convinced that the Diesel engine shows a very high degree of efficiency and economy. However, to illustrate this point more forcibly and put the matter upon a quantitive basis, an example is chosen illustrating a problem which confronts all of us at times. This is the problem of buying new machinery either to extend present capacity or to replace machinery no longer economical. When this problem presents itself,— as it often does in the Community Water Service, — a comparison is set up between the cost of operating with the existing plant and the calculated cost with other forms of power. About two years ago this comparison was formulated for one of our plants. This plant contained 3 horizontal tubular boilers of about 125 h.p. each and 2 horizontal duplex triple-expansion pumps. The equipment had a sendout of 3 m.g.d., was in very good condition, and was housed in a beautiful building.

With the thought that the existing economy might be improved, the comparison shown in Table 1 was made.

The figures in Table 1 are not hypothetical, but were tabulated at the time the study was made. The last column was added after the Diesel plant had been installed and operated. The values in the first column were obtained by averaging the results of the last five years of steam operation. It will be noted that the total operating costs amounted to $28 944. The first cost of the plant is not shown for the reason that a twenty-year old value would not be very enlightening today; nor would the same equipment be installed in a new steam plant.

The second column represents an estimate of the operating costs to be expected if motor-driven centrifugal pumps were installed and power was purchased at 2c. per kw.-hr., the best rate obtainable. It will be noted that the yearly operating cost would be in the neighborhood of $28 760 as against $28 944 for the existing steam plant. Clearly, there would be no advantage in making this change. It should, of course, be borne in mind that the cost of current may be materially cheaper in some localities than at this particular property. It should be noted, however, that power, to beat the final

figure in the last column, would have to be bought at approximately 1.1c. per kw.-hr.

The third column represents an estimate for the Diesel installation. This shows a total operating cost,— the figure in which operating men are most interested,— of $16 730, or an operating saving over the existing steam plant of over $12 000 a year.

TABLE 1.— STEAM — ELECTRIC — DIESEL COMPARISON.

No.	Item.	YEARLY COST — DOLLARS.			
		Steam.*	Electric.†	Diesel.†	Diesel.‡
1	Coal @ $6.50 per ton.	$12 869	$360	$360	$302
2	Power @ 2c. per kw.-hr.	.....	22 200	.....	.....
3	Fuel Oil at 6.7c. per gal.	.....	.....	7 350	7 034
4	Lubrication.	800	.....	420	496
5	Engine Repair.	1 000 Includes Boilers and Auxiliaries.	.....	400	172
6	Pump Repair.	Included above.	200	150	.....
7	Labor.	13 275	6 000	7 800	5 396
8	Supplies.	1 000	.....	250	398
9	Operating Total.	28 944	28 760△	16 730△	13 798°
10	First Cost□.	.....	7 100	43 500	43 000
11	Fixed Charges — 15 per cent.	.....	1 065	6 525	6 450
12	Operating and Fixed Charges.	.....	29 825	23 255	20 248
13	Million Gallons.	800	800	800	923
14	Average Head — ft.	335	335	335	309
15	Million ft. lb.	2 220 000	2 220 000△	2 220 000△	2 462 044°
16	Operating Cost per million ft. lb.	$0.01304	$0.01295	$0.00754	$0.00560
17	Operating and Fixed Cost per million ft. lb.	.....	$0.01343	$0.01048	$0.00822

*Actual average for five years. †Estimated. ‡Actual for one year. □Less building. △Without auxiliary and light power. °With generator included.

On a basis of fixed charges of 15 per cent. per year, a Diesel engine plant could be justified costing $80 000, retaining the old steam plant for standby purposes only. The estimated price for a Diesel installation was $43 500. Actually, the Diesel plant cost $43 000 in round figures. Adding 15 per cent. of this first cost to the yearly operating cost, a total estimated cost of $23 255 was obtained for the engine plant. This figure compares with a value of $29 825 for fixed and operating costs for a motor-driven plant with purchased power.

In comparisons of pumping plants, all figures are reduced to cost per million foot-pounds pumped. On this basis, the electric plant shows fixed

charges plus operating costs of $.01343, and the Diesel plant, $.01048. No fixed charges for the steam plant have been shown for reasons already given, but it is readily seen that with the steam plant costing nothing to build, the Diesel plant would be the only alternative. It was therefore decided to install a 338-h.p. Diesel engine arranged to drive a 3-m.g.d. centrifugal pump through a 400-h.p. step-up gear. The complete installa-

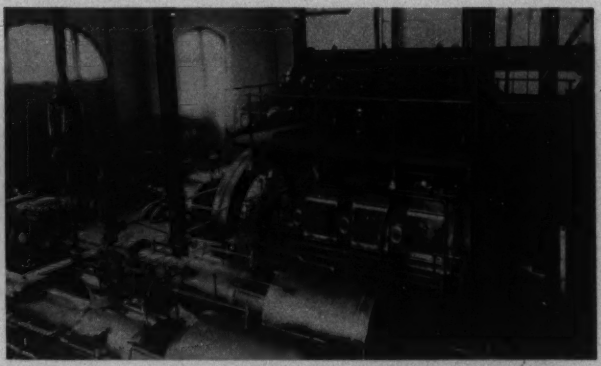

FIG. 1.— DIESEL ENGINE INSTALLATION. THE NEW ROCHELLE WATER CO., POCANTICO DIVISION.
Old Steam Pumps in Foreground.

tion also included a 25-kw. generator, connected to the pump shaft, to generate current for lights, low-lift pumps and other auxiliary power-plant requirements.

The last column of figures in Table 1 represents the actual costs of the Diesel installation. These figures cover the first year's operation. It is seen that the total operating cost was $13 798 as against the estimated figure of $16 730 — a further saving of almost $3 000. This is reflected again in the value for fixed charges plus operating cost per million foot-pounds, which was $.00822. One reason why the actual cost was so much lower than the estimated cost was that the amount of water delivered increased by more than 100 million gal. over the estimated figure.

In order that the writer may be perfectly fair in his statements, attention is called to the item "Engine Repairs." An estimated figure is shown of $400 and an actual cost of $172. It is a well-known fact that repairs to a Diesel engine increase year by year up to the five-year mark, when the maximum is reached. At this period in the life of the machine, considerable maintenance work will be necessary; the engine should then be rendered practically as good as new, when the cost cycle will return to first-year conditions. With this in mind, therefore, the figure of $400 shown in the estimate represents a fair average for this five-year cycle.

Description of Installation. The installation for which the cost analysis was made is illustrated in Figs. 1 and 2. Figure 1 shows the engine. One of the old steam pumps is in the foreground. It is interesting to note the comparative sizes of engine, gear, centrifugal pump and generator. The centrifugal pump is so small that it is completely hidden behind an 8-in. column. The instruments on the switchboard include the speed control

FIG. 2.— DIESEL ENGINE INSTALLATION. THE NEW ROCHELLE WATER CO., POCANTICO DIVISION.
Lubricating-oil Separator in Foreground.

of the engine. This speed control allows a speed variation sufficient to provide for the whole capacity range at the pressure maintained in the main. A variable-speed motor would be required to give this same flexibility to a motor-driven pump. Even so, the losses ensuing from variable-speed motor-control will be considerably greater than is the case with variable-speed Diesel-operation.

Figure 2 gives another view of the engine. In the foreground is the lubricating-oil separator, which operates continuously. To preserve good lubrication, a separator of this sort is one of the most essential auxiliaries of a Diesel plant.

In concluding the description of this station, it may be stated that the duty of this plant as actually found in the guarantee test was 354 400 000 ft.-lb. per 100 lb. of fuel consumed, or slightly better than the guaranteed duty of 348 174 500.

Other Installations. Installations containing engines driving centrifugal pumps through step-up gearing are not so uncommon as one might believe.

Table 2 shows the results obtained in some of the Community Water Service Company plants using oil engines.

TABLE 2.— ECONOMIES FOR DIFFERENT TYPES OF DRIVES.

	Plant No. 1.	Plant No. 2.	Plant No. 3.	Plant No. 4.
Type of Plant.	Pump Geared Centrifugal	Pump Geared Triplex	Electric Generator and Motor	Air-Lift and Triplex
Type of Pump — Low Lift.	None	None	Centrifugal	Air-Lift
High Lift.	Centrifugal	Triplex	Centrifugal	Triplex
Pump Drive — Low Lift.	None	None	Electric	Direct Connected
High Lift.	Step-up Gear	Step-down	Electric	Belted
Number of Engines.	1	1	2	1
Horse Power.	338	40	360	60
Gal. per Day — Low Lift.	.....	.....	1 900 000	125 000
High Lift.	2 880 000	700 000	1 860 000	125 000
Total Head in ft.— Low Lift.	.....	.....	35	100
High Lift.	307	190	286	248
Million ft.-lb. per 100 lb. Fuel Oil.	324	264	205	148.6
Operating Cost per million ft.-lb.	$0.00515	.....	$0.00723	$0.0242

These figures are taken from our records for the month of May, 1929. They should serve as fair examples since this month is neither the lightest nor the heaviest of the year.

Table 2 exemplifies the relative economies of different types of drives. In this table Plant No. 1 is the one previously described; Plant No. 2 contains a 40-h.p. engine direct-connected to a triplex pump; Plant No. 3 has two 360-h.p. engines direct-connected to generators which supply current for operating motor-driven pumps; and Plant No. 4 has a 60-h.p. engine direct-connected to an air compressor which furnishes air to operate the air-lift pumps, and belted to a triplex pump for high-lift pumping.

It will be noted that the direct gear-driven installations are the most efficient and that the air-lift installation is the least efficient.

Table 3 completes the picture of economy by comparing the costs of steam plants, purchased-power plants, and Diesel plants. Three good

TABLE 3.— AVERAGE OPERATING COST OF STEAM, ELECTRIC AND DIESEL PLANTS.

	Steam.	Purchased Power.	Diesel.
Capacity — m.g.d.	8.17	2.35	2.88
Average Head — ft.	316	341	309
Million ft.-lb. per month.	669 887	207 485	205 170
Efficiency Wire to Water	.....	71.2%	.....
Coal — Tons per Month	620	.....	.....
Operating Cost per million ft.-lb.	$0.00818	$0.0063	$0.00515

average plants operated by the Community Water Service Company have been selected powered by steam, electricity and Diesel engine; the Diesel installation being the plant described earlier in this paper.

These records were also taken for the month of May, 1929. The steam plant selected contains triple-expansion, Corliss-valve pumping-engines and is located where coal can be delivered in the bins for approximately $3.33 per short ton. The purchased-power plant buys current for approximately 1¼c. per kw.-hr.

It may be said, however, that these figures do not indicate that Diesel engines should always constitute the equipment to be installed in any station under all conditions. If Diesel engines would fit every case there would be no necessity to set up any figures in advance. When the Community Water Service Company investigates any particular situation it does so with an entirely open mind and without any desire to install any particular kind of equipment. It often appears that equipment of a certain kind, which does not exactly fit the case, is installed due to the particular desires and prejudices of the purchaser. These perhaps excluded the Diesel engine when this type of equipment should have been installed.

Reliability. Those of us who have operated Diesel equipment for a number of years do not doubt its reliability; but it is hard to overcome this doubt unless one has actually had the experience. The writer knows this from his own case, for he well remembers what anxiety was felt over the purchase of the first Diesel engine he was expected to operate. This engine was installed in 1914 and is still in operation today. The economy today is no doubt about the same as in 1914.

The use of the Diesel engine could not have attained its present height if the reliability in practice had not matched up with other types of prime movers. It is significant that Diesel engines are found in ice plants, flour mills, paper mills, dredges, railroad locomotives, drainage and irrigation plants, central stations, rock quarries, glass factories, printing establishments, office buildings, hotels, canneries, yachts, tow boats, freighters and liners, not to mention many other recorded industries.

It is a matter of record that over half of the new ship tonnage under construction the world over will have Diesel propulsion. Everyone knows that at sea property, and life itself, depend upon the reliability of marine propulsion.

In this connection, Mr. Goos, Engineering Director of the Hamburg-America Lines says in a published statement that, "In general, the very numerous Diesel plants on ships are reliable. We have ships which have been in service many years making voyages to the Far East regularly. They come back from a five months' voyage and in three days are ready to start on their outward trip." Mr. Goos' opinion is not at all unique among shipowners and operators.

At the Toronto Convention of the American Water Works Association Dabney H. Maury made the remark that Diesel engine plants are more

reliable than steam plants; and the following is a statement by C. O. Romig, who manages one of the Community Water Service Company's plants containing two 360-h.p. Diesel engines. "We have come to the conclusion that most Diesel engine troubles can be avoided by inspecting the parts that can fail. An interested engineer rarely needs to be in trouble. We may have more trouble during the next four years than we have had during the past, but to offset this, we know better how to take care of the engines and where to look for trouble."

The installation referred to has duplicate units,— which is the case with all well-designed plants no matter what the prime movers may be. Since these engines were installed four years ago, pressure has never been off the mains. There has never been a moment when one or the other of the engines has not been in operation. The success of this plant is largely due to the good care and attention given these engines by Mr. Romig and his operators. Such care is essential in any plant,— steam, electric or Diesel.

The geared plant frequently referred to in this paper has been shut down only once during the past year because of engine failure. The trouble in that instance was due to the failure of a mechanical lubricator serving the air compressor. A compounded oil was used and this attacked the metal of the lubricator. This sort of trouble had never been encountered before, and the operators were not prepared for it. The manufacturer of the lubricator has changed his design to take care of this oil condition, and this trouble probably will not reoccur.

In conclusion, it may be said that if duplicate Diesel engine equipment is installed in any plant no complete shut-down should occur if the machinery is given good care and attention, and that the reliability of Diesel engines under these conditions will equal that of any steam equipment and will exceed that obtained with purchased power — especially so if the power comes in over long transmission lines, as is the tendency today.

DISCUSSION.

P. S. WILSON.* The relative suitability of Diesel engine power as compared with other forms has been the subject of much discussion. Mr. Couch has very ably presented certain views on this subject as they have been developed by his own experience and the experience thus far of the organization to which both he and the writer belong.

It is believed that Diesel engines can provide a source of power at least as reliable as any other form of power, provided equally complete consideration is given to this feature in the design and operation of the plant. Duplication of units and their auxiliaries must be provided, the same as in steam or electric plants, and skill and forethought are necessary in opera-

*Superintendent of Operation, Community Water Service Company, New York, N. Y.

tion. These things being made equal, there is no reason why the advantages of Diesel power under certain circumstances should not be utilized.

In connection with a discussion of the reliability of Diesel engines a case which has recently come to the writer's attention is of interest. The water-supply company in question has several small pumping stations in rather widely separated locations. These stations are powered by semi-Diesel engines of various sizes, under 100 h.p. each. It has been found practical by the company to operate these stations without a constant attendant. The engines once started, are visited once or twice a day to attend to lubrication, fuel supply, etc. The rest of the time the engines operate without being watched. This method of operation has been followed for a number of years. During this period, only a reasonable number of breakdowns have occurred, some of which, at least, could not have been obviated by the presence of an attendant. It is admitted that some of these breakdowns have resulted in greater damage than would have been experienced if an attendant had been present, but the difference in cost has not nearly equalled the saving in labor charges. These plants encroach upon the field for which electric motors alone have been usually considered suitable. While such methods of operation are not usually to be recommended, the fact that they have been followed with apparent success, in at least this case, is of interest.

As to cost, the statement may be made that in medium-sized plants, which are too small for the full possible economy of steam, and in locations where electric power is not distinctly low-priced, Diesel power most certainly should be seriously considered.

Another consideration in the choice of power, particularly for water-works plants, is the suitability of the equipment for use in or near residential sections where noise and dirt are highly objectionable. It has been our experience that Diesel engines may be considered far more suitable than steam in this respect, and, except for space required, at least the equal of electric-motor drive.

A Diesel plant may be entirely free from the smoke and dirt which are almost unavoidable with steam unless it is oil fired. The exterior of the buildings may be made and kept as attractive and pleasing as desired from an architectural viewpoint.

As to noise, the Diesel engine may be muffled on both intake and exhaust to any extent desired, and without appreciable loss of power. In the case of the plant described in detail in Mr. Couch's paper, the requirements as to silence of operation were not particularly severe. The Maxim silencers which were used with the engine were not the most efficient which could have been obtained, and yet one must listen carefully to detect the sound of the engine from any point outside the building. We were assured by Mr. Maxim that by slight additional expenditure any further degree of muffling might be accomplished.

In the case of gear-driven units, either high or low speed, the sound

of the gear is a real factor to be considered when extreme quiet is desired, yet even the gear hum may be reduced, we believe, to a point where its sound is at least no more objectionable than that of electric motors. The writer's company has in operation one electric-driven pumping-plant where the hum of the motors has been the subject of complaint. It is our belief that such sounds may be sufficiently confined, when necessary, by suitable housing.

ELBERT WHEELER.

Elbert Wheeler died at his residence in Nashua, N. H., on Tuesday, June 10, 1930. His passing ended a career which for nearly half a century had been interwoven with the upbuilding and progress of that city, its institutions and the general welfare of its people.

General Wheeler was a native of Concord, Mass., where his people had resided for many generations. He was born on September 18, 1849, and was the son of Edwin and Mary (Rice) Wheeler. He was a descendant on the paternal side of George Wheeler, who came to this country early in the seventeenth century and settled at Concord, Mass., in the district known as Cranefield. (Tolman.)

After attending the public schools of Concord, he was appointed to the United States Military Academy at West Point in the class of 1875, becoming a lieutenant in the First United States Regular Army Artillery Regiment. He was assigned to duty first at West Point, and later at Fort Adams, R. I., Fort Sill, Indian Territory, and Washington, D. C.

In 1877 General Wheeler resigned from the Army to enter business in Laconia, N. H., which he left in 1881 to make his permanent home in Nashua. He engaged quite widely in water-works engineering, building and operating plants in various parts of the country; became treasurer of several water companies, of the Wheeler Reflector Company, and of the Nashua Light, Heat and Power Company.

During his brief residence in Laconia, following his retirement from the Army, General Wheeler organized the Belknap Rifles, of which he was commissioned captain. This company, history records, together with the old Nashua City Guards made possible and brought into being the first real brigade "and which has become the New Hampshire National Guard. He was commissioned as Inspector General, with rank of Brigadier General, in which office he continued until June 28, 1902."

Outside his business and military associations, General Wheeler found satisfaction, in coöperation with his wife, in generous support of good causes for the welfare of their fellow citizens, and particularly in helping deserving youths to continue their studies in school and college, when such studies might otherwise have been denied them by lack of adequate financial resources. He served on the Nashua Board of Education from 1885 to 1887, the Board of Trustees of the Nashua Public Library, as member of the New Hampshire Legislature in 1923, and later as Trustee of the New Hampshire State Hospital.

General Wheeler was a member of the Eastern Yacht Club of Marblehead Neck and of the Exchange Club of Boston. In recent years he had withdrawn gradually from his numerous business affiliations, though

continuing as Vice-President and Director of the Nashua Trust Company. He was one of the founders of the Nashua Country Club and served as its President.

General Wheeler married Miss Clara M. Roby, elder daughter of Luther H. Roby and Eliza Campbell Roby of Nashua on June 22, 1875. Mrs. Wheeler died in 1916.

WILLIAM WHEELER.

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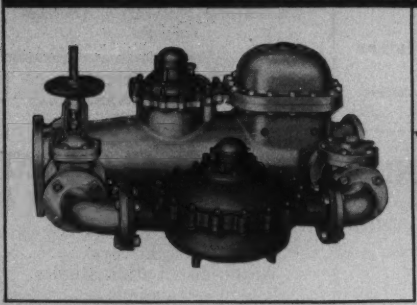
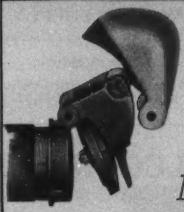


The Hersey Detector, or Fire Service Meter. Equipped with the new Hersey Counterbalanced Lever Valve shown at the right.

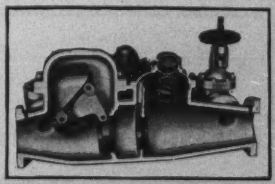


No **HERSEY Detector Meter** ***has ever failed***

FOR dependability no fire service meter can excel the Hersey Fire Service Meter. Not one of the 8000 in over 800 water departments has ever failed to operate in an emergency.

This meter is equipped with the new Hersey Counterbalanced Lever Valve. This valve will not "flutter" at the "cross-over" point. It is either tightly seated or definitely open. Accuracy for all size flows is maintained. Loss of head prevented. Free passageway through the meter assures full pressure for the sudden opening of a fire sprinkler head or hydrant.

Hersey is the pioneer manufacturer of fire service meters. This meter is approved by the Chicago Underwriters' Laboratory, Inc. Let us estimate on your requirements.



Interior view of the Detector Meter. Note the simplicity and heavy construction of this meter. The Counterbalanced Lever Valve is shown in nearly full open position.

HERSEY
WATER METERS

HERSEY MANUFACTURING COMPANY, *Main Office and Works:* Corner E and 2nd Sts., South Boston, Mass. *Branch Offices:* NEW YORK CITY, 290 Broadway; PORTLAND, ORE., 475 Hoyt Street; PHILADELPHIA, PA., 314 Commercial Trust Bldg.; ATLANTA, GA., 510 Haas-Howell Bldg.; DALLAS, TEX., 402 Praetorian Bldg.; CHICAGO, ILL., 10 So. LaSalle Street; SAN FRANCISCO, CAL., 690 Market Street; LOS ANGELES, CAL., 450 East Third Street.

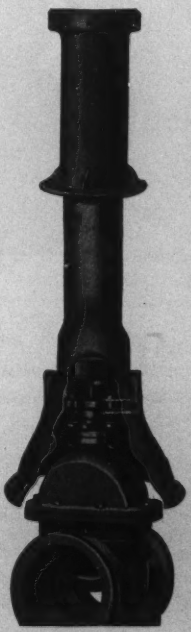
BINGHAM & TAYLOR'S Sliding Type Service and Valve Boxes are meeting with the approval of many New England Waterworks officials.

The cuts shown are our two and three piece sliding type adjustable valve boxes.

The flange on the bottom of the top section can be located any distance from the top.

We carry a complete stock on hand at all times.

Wire, phone or write us when you are in a hurry for a shipment.



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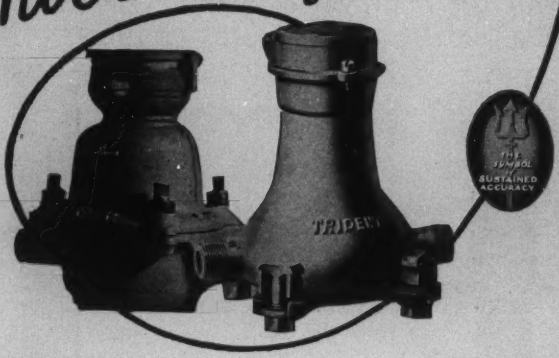

TRIDENT and Lambert Interchangeable Unit Parts are of absolutely uniform accuracy. They are the result of machines and manufacturing methods of minute precision, permanently maintained. That means that they will fit exactly into a Trident or a Lambert main meter casing of a generation ago, of today or of a score of years hence — and that means these meters, in spite of time and improvements, never become obsolete.

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Yesterday, TODAY, Tomorrow

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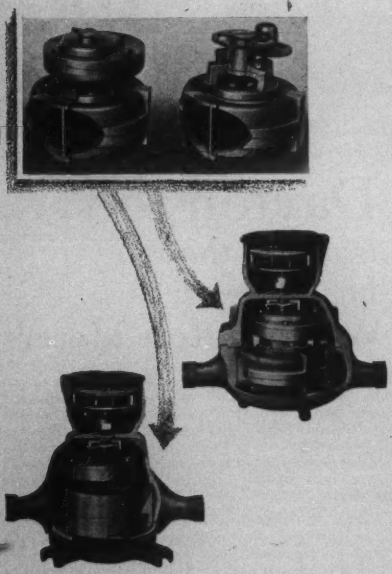

Intermediate Trains

ARCTIC and Tropic meters are equipped with either the open train or the oil enclosed train. The former embodying monel metal wheels, pinions and spindles, all bronze parts heavily coated with tin to prevent corrosion. The oil enclosed intermediate train is filled with special grade of oil to protect the working parts. Either type is furnished at the option of the customer.

Both intermediate trains are entirely separate from the meter case, mounted on a two part measuring chamber and are interchangeable one with the other.

Pittsburgh Equitable Meter Co.

Main Office and Works—Pittsburgh, Pa.

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Note the frost clamps on the main case flange. When the meter is subjected to the action of frost, these clamps yield gradually, thus preventing shock to the operating parts. Furnished on one-inch and smaller sizes of disc meters.

Dayton too . . .
is one of the big users of Worthington Meters

HERE is a representative modern American city with up-to-date public service, in which Worthington equipment plays a prominent part. Dayton's Municipal Pumping Station is Worthington-equipped with eight centrifugal pumps having a capacity of 87,000,000 gallons per 24 hours. A large part of the consumption of this water supply is measured by the thousands of Worthington Meters installed in buildings of all classes throughout the city.

For over 70 years, Worthington has manufactured water meters. During that period, development has kept pace with the demands of changing conditions. Worthington Meters are thoroughly modern in design and are carefully constructed of durable materials. Accuracy and long life are built into every meter.

Bulletin W-900-B3 contains detailed information on Worthington Cold Water Meters of all types. *May we send you a copy?*

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COMPRESSORS
Stationary and Portable
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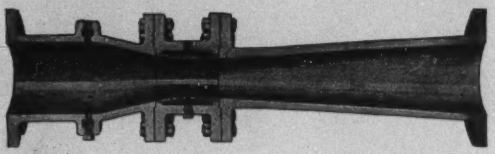

The Venturi Tube

In 1891 the Venturi Tube was new. Those Engineers who knew of it hoped it would help solve the difficult problem of measuring the flow of water in large pipe lines.

In 1929 the Venturi Tube is accepted by Engineers as the most dependable and accurate means of measuring flow through pipe lines.

It may be worthwhile, however, to summarize a few of the important advantages of the Venturi Tube:

1. The flow is guided at all points.
2. The inlet and throat pressures are taken off at definitely fixed points; the annular pressure chambers assure the use of true average pressures.
3. The Venturi throat is accurately centered in relation to the rest of the pipe line.
4. The friction loss through a Venturi Tube is the lowest of any differential producer. The Venturi Meter, then, operates on a greater differential with less friction loss, and is a more powerful instrument with a wider measuring range than other meters.
5. The coefficients of the Venturi Tube have been definitely established in numerous calibration tests of tubes ranging in size from 1 inch to 8 feet in diameter.

VENTURI
"VENTURI" Registered

BUILDERS IRON FOUNDRY

"Builders of the Venturi since 1891"

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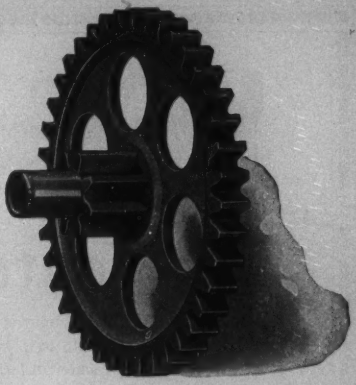


Announcing...

A new gear patent and what it means to you!

OF utmost interest to the Water Works Superintendents are the new Letters Patent, just issued to the Buffalo Meter Company covering gears "with a tough bronze inner core and with an outer wear-resisting chromium shell."

This new patent gives the Buffalo Meter Company the exclusive right to manufacture a gear whose outer shell is chromium...one of the hardest metals known. Now, just what does this mean to the Water Works Superintendent?

In the first place . . . the chromium shell is so hard that there is no wear-out to it. And water, no matter what its chemical properties, will not corrode chromium.

In the second place, the chromium shell gear renders the oil enclosed gear obsolete. The gears are self lubricated by the water passing through the gear chamber. Because of the hardness and smoothness of the chromium shell gear, there is no need for further lubrication.

In addition to the above features of the gears used in Niagara and American Water Meters, the key-seated and riveted gear, the hard rubber or jewelled bearing, the enclosed pinion, and the separation of the gears in the frost bottom type of meter, are your added guarantees of perfection in the manufacture of Buffalo-Made Water Meters.

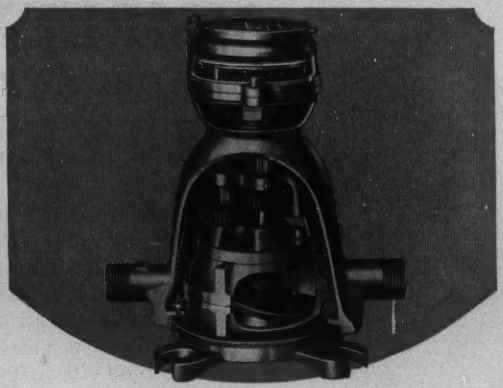
In buying Water Meters for your municipality...you should have a full appreciation of the quality being built into Buffalo-Made Meters. To gain this appreciation, send for the latest Niagara and American Water Meter Catalog. Simply address...

BUFFALO METER COMPANY

2889 Main St., Buffalo, N. Y.

NIAGARA (IRON CASE) *and* **AMERICAN** (BRONZE CASE)

Water Meters



King F. P. Water Meter

It has taken sixty years' experience to build water meters the UNION way.

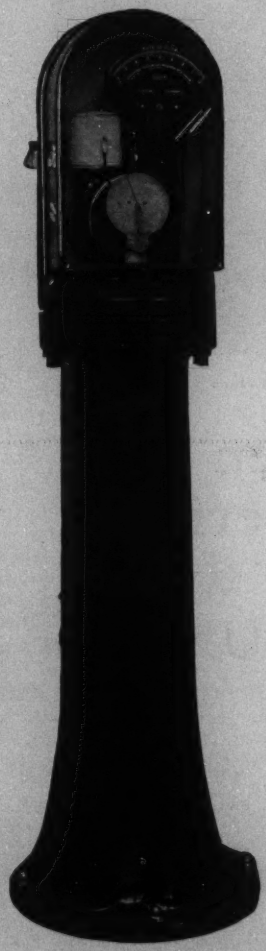
Union Water Meter Co., Worcester, Mass.

New York: 50 Church St. Philadelphia: 424 Bulletin Bldg.

UNION

Water Meters - Easy Turning Stops - Chronometer Valves

Presses for Lining Pipe - Pressure Regulators - Alarm Signals



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VENTURI TYPE
METERS

Indicate the flow on a uniformly graduated dial.

Record the flow on a rectangular chart with uniform graduations.

Totalize the flow on a five-dial totalizer, so designed that the last figure can be read with accuracy on a much larger scale.

They may be furnished for floor stand, wall bracket or panel mounting.

May be used for pump discharge — gravity supply — in the Filter Plant — or Sewage Treatment Works.

Simplex Meter Registers may be checked at any time while in service by use of apparatus furnished as standard equipment — an exclusive feature of the Simplex Meter.

Simplex Meters are the choice of many who value quality and accuracy above initial cost.

Write for data.

Simplex Valve and Meter Co.

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"WATCH DOG" WATER METERS

ACCURATE *DURABLE*

DISC, CURRENT AND COMPOUND TYPES

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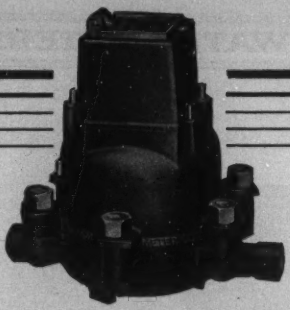

METERS

The best is none too good for the modern water works operator. Pretty good is no longer good enough. For that reason modern meters are so carefully made and adjusted that it is getting harder and harder to make a choice among them. But there are always a few points of comparison, where one meter is better suited than another to your special conditions.

The NASH

The NASH, owing to its extra strength, its fine bronze construction, and all its well designed and substantial parts, is more adaptable to difficult service than any other disc meter. The NASH also has the simplest and most economical of all frost protection features — a breakable flange washer, always effective, easy to replace, and costing almost nothing.

NATIONAL METER CO.

299 BROADWAY NEW YORK

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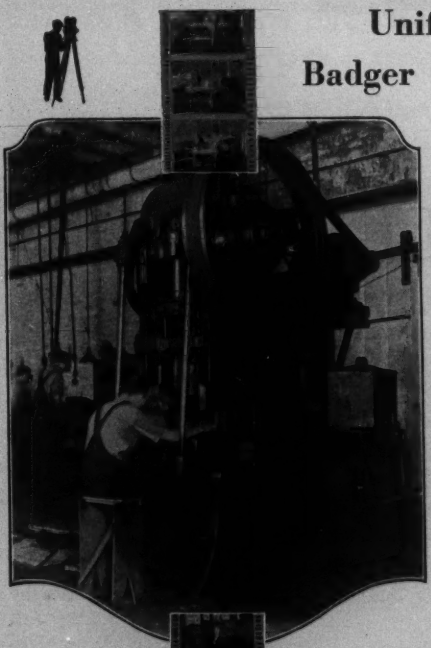
Modern Machinery Assures Uniformity of Badger Meter Quality

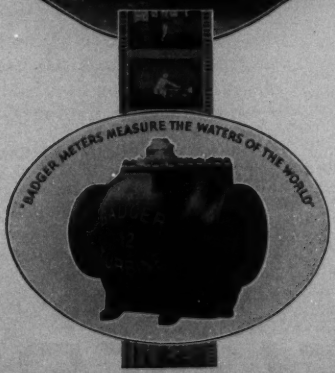


The better the tools, the better the work . . . and by the same token, Badger's modern manufacturing facilities are responsible for the accurate and dependable field performance of Badger Meters, as well as their surprisingly low maintenance costs.

Batteries of precision machines produce each and every part . . . large and small . . . all to the required dimensions . . . uniformly accurate. In Badger Meters you will find a minimum of working parts, assembled by units. This construction provides ease of access to all working parts when necessary. Know Badger Meters better.

There is a Badger for every service from the small ⅝" disc meter to the large 10" compound and 12" Turbine Meter. Progress is shown in the Badger Movie.

A showing is available without obligation



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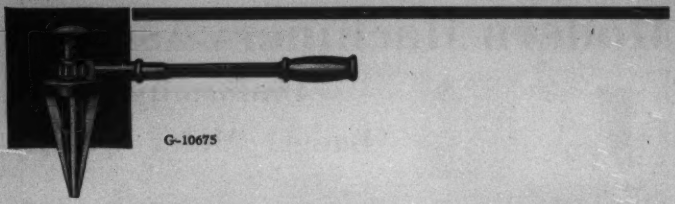


G-10675

For improved efficiency use these finer

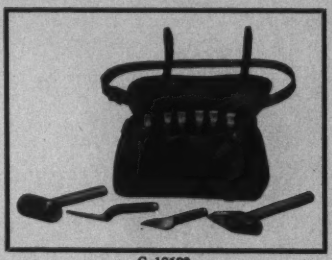
MUELLER TOOLS

MORE OFTEN than not the ability of a man to turn out a job in a creditable fashion is determined by the tools he uses.

Even the most skilled workman can't turn out an A-1 job if his tools are out of tune to his ability.

Why not, then, make the most of your ability by using the tools that fit your hand like the keenest instrument poised in the hand of the master surgeon?

Mueller tools are made for men with pride in the craft they follow. Nothing has been spared to make them the most efficient — the most durable and the most convenient to use. All metals come from tested batches from laboratory controlled sources. All forgings are done by hand in the same time-honored manner approved by centuries of experience.



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The Pipe End Reamer and the Water or Gas Main Calking Set, illustrated, are typical of the highest type tools Mueller has had the pleasure of offering its friends for a period of more than seventy years.

Write us for full information. It will be gladly sent.

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A few reasons why we solicit your inquiries on Water-Works Pumping Equipment:

First. — We make a specialty of furnishing Complete Water-Works Pumping Units of all types.

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Fourth. — Every unit installed to date has exceeded its guarantee and has been completely accepted.

Remodeled Pumping Station at Bridgewater, Mass., completely installed by F. A. Mazzur Co., Inc. Barbour & Dixon, Eng'r's.

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A proven product developed to meet the demand for a lead substitute which will make joints that are reasonably tight from the start.

A few of its numerous features are quick melting, rapid pouring, no caulking, elimination of the necessity for deep bell holes, cleanliness, and freedom from moisture. RADIAL CRACKS DO NOT OCCUR IN MINERALEAD JOINTS.

MINERALEAD on a job arouses enthusiasm in the engineer, contractor, and laborer alike. IT MORE THAN SATISFIES.

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Distributed in New England by

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OF EVERY TYPE

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The first named is most generally used and is most easily adjusted. The Bolted has a safety factor of 15 to 1; and the Hackensack is extra long, requiring lead only at its extreme ends.

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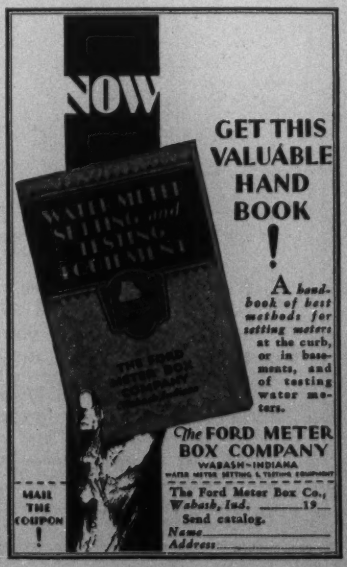
THE A.P. SMITH MFG. CO. *East Orange, N.J.*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A *handbook of best methods for setting meters* at the curb, or in basements, and of testing water meters.
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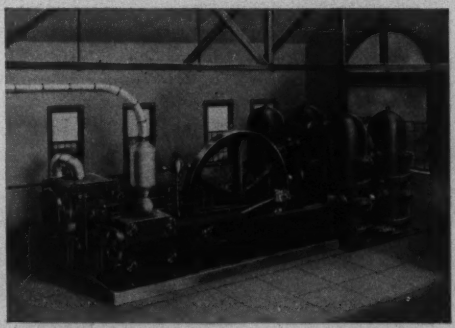
BURLINGTON, IOWA, U. S. A.

Builders of High Duty Pumping Engines



Murray High Duty Crank and Fly Wheel Pumping Engine, Opposed Type

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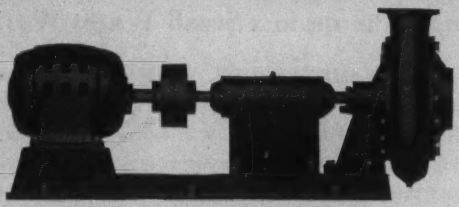
will be glad to show you the superior design and excellent workmanship of the new 3 M. G. D. Murray Pump in the Arlington Pumping Station of the Metropolitan District Commission. Exceptional operating results are being obtained as shown by the official duty test which exceeded the guaranty by a substantial amount.

PLEASE SEND US YOUR SPECIFICATIONS AND CALLS FOR BIDS



Fairbanks-Morse Horizontal Trash Pump direct-connected to Fairbanks-Morse Ball-Bearing Motor

Now a great advance in sewage pumping

For the first time a pump has been designed that will handle fluids containing the fibrous and stringy matter found in sewage — without clogging, without preliminary screening, and without the excessive power consumption that characterizes the less satisfactory open impeller type of pump.

The secret of this pump's success lies in the design of the simple two-blade impeller. The blades of the impeller have well-rounded entering ends and are well filleted with the shrouds or sides. Thus a rag or other trash does not find sharp projections on which to catch and cause clogging. Since the impeller is the enclosed type, foreign matter, in passing through, does not come into contact with stationary side plates, but is promptly discharged through one of the large ports into the pump case. In this way power is conserved and efficiency increased.

This pump was designed by Mr. A. B. Wood who has been serving the city of New Orleans and other municipalities in the capacity of consulting engineer. It was originated by Mr. Wood to cope with the very unusual sewage problems found in New Orleans and met with immediate success.

Fairbanks-Morse Trash Pumps are made in two types, horizontal and vertical. They are ruggedly built to cope with severe service and at the same time they possess such refinements as ball bearings, smoothed fluid passages, and other marks of quality construction.

Ask for bulletins giving complete details.

FAIRBANKS, MORSE & CO., Chicago

28 branches in principal cities at your service.

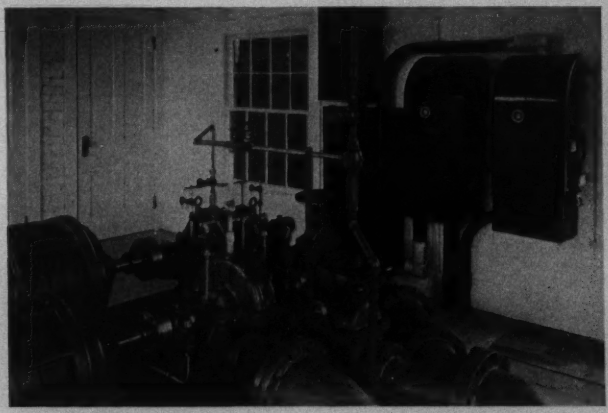
FAIRBANKS-MORSE

PUMPS · DIESEL ENGINES · MOTORS

AN INTERESTING DE LAVAL INSTALLATION

Centrifugal Pumps in a Small Water Works Plant

THE TOWN OF MIDDLEBURY, VERMONT, which was entirely dependent for water upon a mountain reservoir, decided in 1928 to supplement this supply with a pumping unit taking water from natural springs. A De Laval was the choice and the service obtained was so satisfactory that the Town decided to depend almost entirely upon the springs. After one year's operation, another De Laval of larger capacity was installed to meet the demand in dry months and also as further fire protection.



Two De Laval motor driven two-stage series type pumps installed in the Palmer Spring Pumping Station at Middlebury, Vermont.

We contract for complete installation including
all piping and electrical work

TURBINE EQUIPMENT CO. OF NEW ENGLAND

80 Federal St., Boston, Mass. **Phone LIBerty 5993**

Engineers and Contractors for complete
De Laval Waterworks Pumping Equipment

Write us for full details and specifications.

LESS THAN 1% FOR MAINTENANCE

20 minutes... a small wrench... a screw driver... to take apart a W & T unit, clean and re-assemble it.

Seven years ago the largest chlorinating installation in the world was made at the Easterly Sewage Disposal Plant, Cleveland, Ohio. In seven years annual maintenance costs have never exceeded 1% of the low initial investment! Today these machines are in perfect working order.

The simplicity of the W & T Vacuum type Chlorinator is largely the reason for this admirable record. A small wrench, a screw driver—and in 20 minutes this machine can be dismantled, cleaned and re-assembled. No technical knowledge is necessary.

Day in and day out, in more than 6,000 American municipalities, W & T equipment is giving this same satisfactory, practically cost-free service.

Our engineers will gladly recommend suitable equipment to meet your specific requirements and to figure for you exact installation and operating costs. Let our staff be of service. There is no obligation.

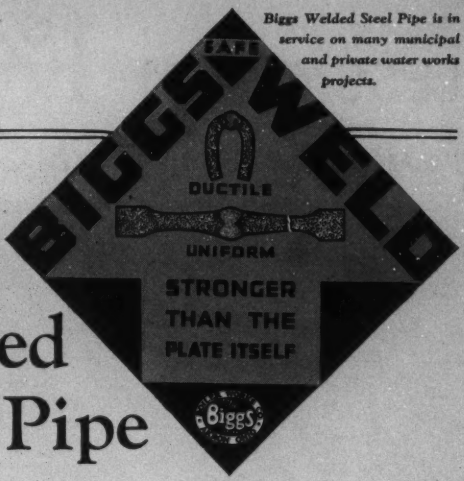
WALLACE & TIERNAN CO., Inc.
Manufacturers of Chlorine Control Apparatus
NEWARK, N. J.
Branches in All Principal Cities

A PRODUCT OF

WALLACE & TIERNAN

The Only Safe Water *is a Sterilized Water*

Biggs Welded Steel Pipe is in service on many municipal and private water works projects.



Biggs Welded Steel Pipe

Of the materials available for pipe line construction, none compares with steel in structural strength. Of the several types of steel pipe, Welded Pipe is the strongest, is the most efficient, and possesses the greatest carrying capacity.

Biggs Electrically Welded Steel Pipe, 30- to 96-in. diameter, is being preferred more and more by leading water works engineers, especially where operating conditions are severe. It is replacing many pipe lines of a less dependable character.

Produced under procedure control, Biggs Welded Pipe insures a uniform product. It offers maximum structural strength (100% joint efficiency), a smooth interior, a practical absence of maintenance, and complete dependability. It guarantees a safe, permanent, economical, efficient pipe line.

Biggs Welded Steel Pipe has been subjected to tests impossible with any other type of conduit. Countless tension, bend, torsion, and hydrostatic tests have conclusively shown that "the Biggs weld is stronger than the plate itself." Data will be furnished on request.

THE BIGGS BOILER WORKS COMPANY

(30-in. diameter pipe and larger, welded or riveted)

Seneca and Case, Akron, Ohio. New York, Detroit, Chicago.

Inspectors for New York, Detroit, and Boston approving sections of Biggs Welded Steel Pipe after test. The contracts involved about 50,000 feet of 36-in. to 72-in. diameter pipe for installation in these cities.

PRECALKED JOINT PIPE

CAST IRON PIPE

Bell and Spigot—Sand Cast—Modern Weights

Sizes: 1¼ through 12 inches. Lengths to 16 feet

Boston stocks. Furnished with or without Precalked Joints

McWane Cast Iron Pipe Company

Eastern Office: 123 South Broad Street Philadelphia

Sales Representatives: FRED A. HOUDLETTE & SON 40 Central Street, Boston Eastern Mass., Me., N. H.

General Offices: BIRMINGHAM, ALA.
Foundries: BIRMINGHAM, ALA., PROVO, UTAH

Main's Hotcoating for the inside of standpipes and water tanks, will stop all pitting and corroding, and is guaranteed for seven years.

Also

Main's Coverall Salt Air Paint, for the outside of standpipes and water tanks, guaranteed for four years.

M. B. MAIN **Box 189, Somers Point, N. J.**

The "COREY" Hydrant

Why you should use GENUINE COREY HYDRANTS

Water to Nozzles quicker than other Hydrants.

Standpipe can be removed and replaced without shutting off water in main.

Ease of operation insured by knuckle joint principle.

Only 13 turns to completely open or completely close, but full flow with only 4 turns.

Nozzles screwed in — not leaded.

Can be lengthened without shutting off water.

Will not flood if broken.

Positive Drip — cannot freeze.

Standpipe can be revolved quarter turns — Nozzles always in right direction.

Write for copy of our new Catalog "G."

CHARLES L. BROWN,
New England Sales Manager, Lock Box 2, Northboro, Mass.

RENSSELAER VALVE COMPANY
TROY, N. Y.

NICHOLAS ENGEL

JOHN FOX & CO.

CAST IRON

WATER & GAS PIPES

FLANGE PIPE

Special Castings, Fire Hydrants, Valves

General Foundry and Machine Work

WOOLWORTH BUILDING 233 BROADWAY

NEW YORK CITY

HIGHEST AWARD, GOLD MEDAL,
ST. LOUIS EXPOSITION, 1904

Over 100 Water Departments

use

LEAD-LINED IRON and TIN-LINED PIPES

for their service connections

MANUFACTURED BY

Lead Lined Iron Pipe Company

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PIERCE-PERRY CO.
SUCCESSORS TO
GEORGE E. GILCHRIST CO.
JOBBERS OF
Heating and Plumbing Supplies
Steel, Wrought Iron and Brass Pipe
Water Works Materials
DISTRIBUTORS OF
Hoffman Valves and Controlled Heat Equipment
236 Congress Street, Boston.

We Carry in BOSTON STOCK for Immediate Shipment
CAST IRON BELL AND SPIGOT WATER PIPE AND FITTINGS
FLANGED PIPE in full and short lengths
WROUGHT PIPE
FRED A. HOUDLETTE & SON
(Incorporated)
40 Central Street, Boston, Mass.
Quotations furnished promptly for shipment from Foundry

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Manufacturers of and Dealers in
S. & G. Water Works Brass Goods
Byers' Wrought Iron Pipe
Service and Valve Boxes
Cast Iron Pipe and Fittings
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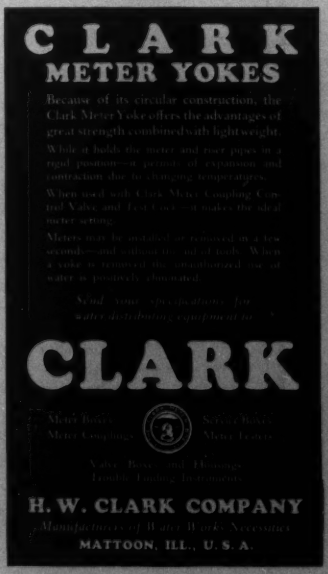
CEMENT LINED SERVICE PIPE
With Specially Adapted Lead-lined Fittings
Also Curb Cocks which eliminate Iron to Brass Corrosion both inside and out.
CEMENT LINED PIPE CO.
LYNN, MASS.

Water Works Contractors and Supply Houses!
Your card may be inserted as above at a rate of $12 per year.

A Classified Directory
of Advertisements is arranged for your convenience in the back of this Journal.


CLARK
METER YOKES
Because of its circular construction, the Clark Meter Yoke offers the advantages of great strength combined with light weight.
While it holds the meter and riser pipe in a rigid position it permits of expansion and contraction due to changing temperatures.
When used with Clark Meter Coupling Curb and Yoke Cock it makes the ideal meter setting.
Meters may be installed or removed in a few seconds and without the use of tools. When a yoke is removed the consumer's line of water is positively shut off.
Send your specifications for water distributing equipment to
CLARK
H. W. CLARK COMPANY
Manufacturers of Water Works Necessities
MATTOON, ILL., U. S. A.

Damage to Hydrants

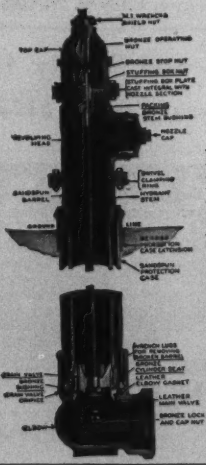
To the Editor:

We have had an epidemic of hydrants that were struck by trucks and automobiles, most of them at street intersections. The repairs have been most troublesome and even costly. Can you suggest some way by which the trouble can be reduced, if not eliminated?

Yours truly,

(*Water Works Engineering*)

Solves the Broken Hydrant Problem



MATHEWS MODERNIZED HYDRANT

Interchangeable with old installations

Broken "Mathews" hydrants are put back into service easily and quickly. Simply unscrew the broken barrel, using the handy extraction tool, and screw in the new barrel—the whole job done easily in thirty minutes or less, without excavating or breaking the pavement. This exclusive "Mathews" feature is a great saver of time, labor and money.

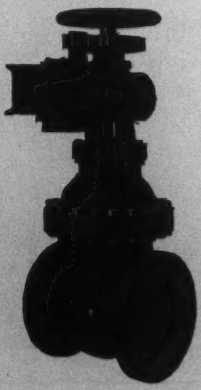
As a broken "Mathews" cannot leak, there is no water waste, and no danger of damage from flooding.

R. D. WOOD & CO.

In business continuously since 1803

400 Chestnut St. Philadelphia

CAST IRON PIPE AND FITTINGS
SAND SPUN (centrifugally cast) and PIT CAST
Reg. U. S. Pat. Off. GATE VALVES



Valves and Fire Hydrants

that are on the line to STAY

WHEN KENNEDY VALVES and Fire Hydrants are installed, they ***stay put.*** Leakage and wear, with their resulting losses and expenses, are conspicuously absent even after long years of service. It's no uncommon record for a Kennedy Product to serve for a quarter of a century or more without requiring any attention other than occasional inspection.

Operating records prove that you can safely standardize on Kennedy Valves and Fire Hydrants. The big Kennedy line makes it easy for you to select a standard type for practically every requirement of size, pressure, material or method of control.

The complete line of Kennedy Valves, Fittings and Fire Hydrants is fully described and listed in the Kennedy Catalog. Send for a copy today to help you make a selection for trial.

THE KENNEDY VALVE MFG. CO.
Elmira, N. Y.
Branches in principal cities

KENNEDY

VALVES~PIPE FITTINGS~FIRE HYDRANTS

THE STANDARD FOR 50 YEARS

Automatic Pressure Control Valves
Feed Water Filters
Portable Fire Hydrants
Hydraulic Engines
Hydraulic Engines—Booster Pumps

ROSS VALVE MFG. CO., INC. TROY, N. Y.

Health and Protection First

Water delivered through dirty pipes may be a MENACE.

Incrusted water pipes mean inefficiency and loss of Fire Protection.

We Guarantee the Results of Our Method of Cleaning.

WRITE US.

National Water Main Cleaning Co.

50 Church Street New York City

HAYES PUMP AND MACHINERY CO.

94 PEARL ST., BOSTON, MASS.

Pumping Plant Contractors

CENTRIFUGAL, POWER, STEAM PUMPS

STEAM TURBINES
WATER WHEELS

ELECTRIC MOTORS
OIL ENGINES

GOLDEN-ANDERSON

Patent Automatic Cushioned Controlling Altitude Valves

We have enlightened many a water user in municipalities, in industrial plants and on railroads, as to the adaptability of these Golden-Anderson Valves, and as to their function of SAVING, and of eliminating troubles.

For automatically maintaining Uniform Stage of Water in Tank, Reservoir or Standpipes. Doing away with the annoyance of Freezing and Float Fixtures inside or outside of Tanks.

"Three Ways of Closing These Valves":
1st —Automatically, by water.
2nd—By Electricity, if desired.
3rd—By Hand

May also be arranged to automatically close when a break occurs in the mains. When necessary they may be so connected as to "work both ways" on a single line of pipe. No valves or fixtures inside or outside.

Sizes to 24 in.

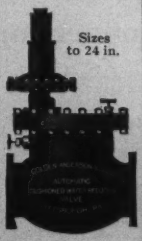
Remember!

"HOSTS OF REFERENCES"
Valves cushioned at all times by air and water
No water hammer or bursting mains

"Made with stop starter attachment for centrifugal pumps"

GOLDEN-ANDERSON
Pat. Automatic Cushioned Water Pressure Regulating Valves

1. Maintain a constant reduced pressure regardless of fluctuations on high pressure side.
2. Perfectly Cushioned by water and air. No metal-to-metal seats.
3. The best valve made for maintaining a constant low pressure where consumption is continuous.
4. Operates quickly or slowly as required — No attention necessary.
5. Positively no hammering or sticking.



Sizes to 24 in.

GOLDEN-ANDERSON
Patent Automatic Cushioned Controlling Float Valves

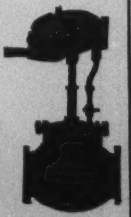
They carry a constant water level in feed water heaters by perfectly controlling the flow of makeup water.

Operated by protected enclosed copper float.

Cushioned by both air and water.

Operate without hammering, sticking or chattering. No metal-to-metal seats. Made angle or straightway.

Sizes 1 in. to 24 in.



GOLDEN-ANDERSON
Pat. Automatic Cushioned Water Float Valves

1. Automatically Maintain Uniform Water Levels in Tanks, Standpipes, etc.
2. Instantly Adjusted to Operate Quickly or Slowly.
3. Floats Swivel to any Angle — Most Satisfactory Float Valves Known.
4. No Metal-to-Metal Seats — No Water Hammer or Shock.
5. Cushioned by Water and Air.

Angle or Globe

Sizes to 24 in.

GOLDEN-ANDERSON
Patent Automatic Double Cushioned Check Valve

Sizes to 24 in. Angle or Globe

Automatically prevents reverse flow of pressure. Perfectly cushioned to prevent shock or hammer. Especially adapted for water works to prevent disastrous reverse flow of pressure due to pumps stopping. Arranged so that quick or slow operating may be obtained.

Golden-Anderson Valve Specialty Co., 1325 Fulton Bldg., Pittsburgh, Pa.

THE CHAPMAN VALVE MANUFACTURING COMPANY

Manufacturers of

Gate Valves Drip Valves

Gate Fire Hydrants

Corporation Cocks Curb Cocks

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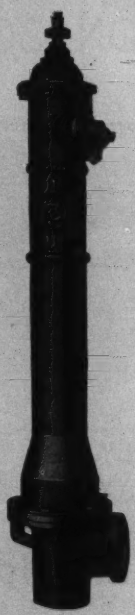


Type of Eddy Hydrant Popularly Used

More Than Sixty Years of Experience Goes Into All

EDDY

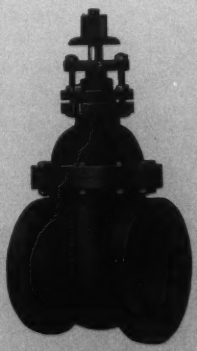
Hydrants and Valves

BUILT TO MEET EVERY EXACTING REQUIREMENT OF WATER-WORKS SERVICE

Practical water-works men instantly recognize the superior features of Eddy products. For instance, with the hydrant.

A damaged valve can be replaced in a few minutes — Water hammer is avoided by the valve closing against the pressure and the use of the cut-off under the valve, which gradually closes it —
Stems cannot be bent in closing the hydrant.
Nothing can lodge on the valve seat to prevent closing of the valve —
The Drip Rod can be removed without interfering with the hydrant in any manner —
The position of the stem of the hydrant indicates accurately the position of the valve —
Whatever can pass the valve opening will pass the standpipe —
No frost case necessary —
All of these points are explained thoroughly in our catalogue, which will pay you to study.

The Eddy Valve, Too



Has its distinctive and individual features. The double disk gates are free to adjust themselves in different positions every time the valve is closed, thereby keeping smooth and tight faces. And two bronze hooks on the ball loosely engage with the gates to prevent them from spreading at the top. The center bearing gates are forced to their seats with equal pressure at all points. There is a good deal more worth knowing about Eddy Valves. Further details will be sent for the asking.

Other Eddy Products

The Eddy line of water-works products also includes horizontal and vertical check valves, foot valves, hydraulically operated valves, indicator posts, etc.
All goods made by the Eddy Valve Company are manufactured exclusively at Waterford, New York.

WRITE FOR CATALOGUE

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WATERFORD, N. Y., U. S. A.

EMAUS PIPE FOUNDRY,
DONALDSON IRON CO.,

MANUFACTURERS
...OF...

CAST IRON PIPE

...AND...

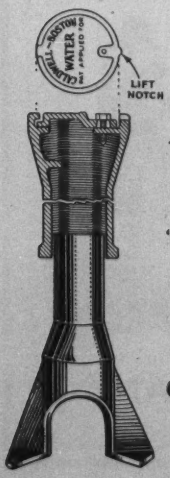
Special Castings for Water and Gas.
Also Flange Pipe, Street Castings,
Manhole Heads and Covers, etc.

J. G. EBERLEIN, President and Treasurer.
J. M. GILBERT, Secretary.

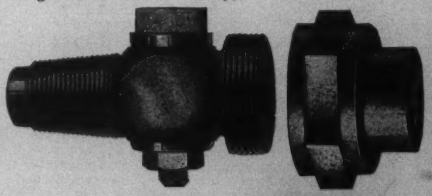
EMAUS,
LEHIGH COUNTY, PA.

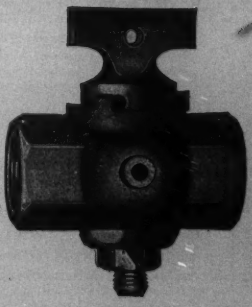
The "BEST" Cast Iron Curb Box

Top section is interchangeable with the "Slide Type" Buffalo Box



No change necessary in wrench or shut off keys





"CALDWELL" Water Works
Brass Goods, Curb and
Valve Boxes

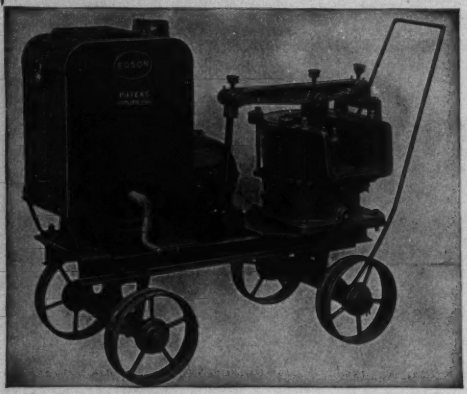
None better and few as good

GEORGE A. CALDWELL CO.
Mattapan Square
BOSTON, MASS.

EDSON MFG. CORP.

DIAPHRAGM PUMP SPECIALTIES

Hand Pumps. Heavy Duty and
Light Portable Power Pump Outfits



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Special Suction Hose

Red Seal Diaphragms

Pump Accessories

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(Formerly Warren Foundry and Machine Co.)

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Telephone, Liberty 9398

CAST IRON PIPE

Bell and Spigot Flanged Pipe
Special Castings
Flexible Joint Pipe Cylinders

Water Gas Sewers Culverts

Works, Phillipsburg, N. J.

LARGE STOCK ENABLES US TO MAKE QUICK SHIPMENTS

LEADITE

Indianapolis Water Co.
has used LEADITE on
150 Miles of Cast Iron Pipe

Mr. H. S. Morse, Manager of the Indianapolis Water Company, Indianapolis, Ind., another of the C. H. Geist Properties, and one of the largest privately owned plants in this country (supplying a population of approximately 400,000) advises us in a recent letter, as follows:

"We have laid 150 miles of cast iron pipe during the past 5½ years in which Leadite has been used as a jointing material. The sizes of pipe ranged from 6" to 36". These pipes have been used under pressures of from 60 to 100 pounds and we have found the tightness of the joints to be satisfactory."

The pioneer self-caulking material for c. i. pipe.
Tested and used for over 30 years.
Saves at least 75%

THE LEADITE COMPANY
Land Title Bldg. Philadelphia, Pa.

No Caulking

National-Boston Lead Co.

800 Albany St., Boston

Agents for

The Celebrated "ULCO"

LEAD WOOL

(Every Atom Pure Lead)

For calking pipe joints under the most difficult conditions.

For overhead joints, or in wet places where the use of molten lead is not only impracticable but dangerous — **LEAD WOOL** may be used to advantage.

It makes an absolutely tight joint which will withstand the highest pressure, yet be sufficiently elastic to allow considerable sagging or settling of the pipe without danger of a leak.

As compared with the poured joint, in this respect, the superiority of **LEAD WOOL** is apparent.

Manufacturers of

Lead Pipe, Tin Lined Lead Pipe, Pure Block-Tin Pipe, Solder, White Lead and Red Lead.

HIGHEST QUALITY SOFT BRANDS

PIG LEAD

Joints that are Stress and Vibration Proof

Unusual situations often met in laying bell and spigot pipe — lines over bridges or railroad crossings — lines to be lowered to grade — are successfully met when the joints are made with Hydro-Tite.

Easy to Prepare

The 8-in. line pictured above is slung across a pond with cables — a span of more than fifty feet.

Every test shows that Hydro-Tite joints will remain perfectly tight when subjected to severe vibration or deflection. If you have never used Hydro-Tite let us tell you more about it. Requires no caulking — 19 years of proven dependability — a real 75% saving and an ever-increasing list of satisfied users.

Write for literature and further information.

Easy to Pour

HYDRAULIC DEVELOPMENT CO.

50 Church St., New York, N. Y.

BOSTON OFFICE & WORKS
296 Boylston St.

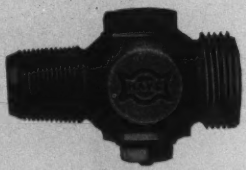
CHICAGO OFFICE
7 So. Dearborn St.

HYDRO-TITE

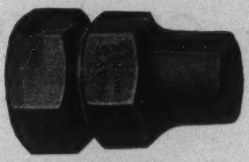
REG. U. S. PAT. OFF.

The MODERN JOINT MATERIAL

The Hays Copper Plumbing Method

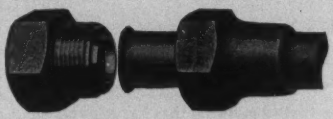


Regular Corporation Stop



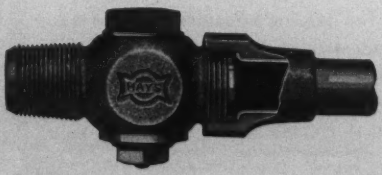
Adapter

In making an installation with Hays Copper Service Fittings the regular Corporation Stops can be used in conjunction with the adapter. It is not necessary to procure new mandrels, as the Corporation Stops are inserted with the regular mandrels, in the usual manner, after which the adapter is attached.



Open View of Adapter

These adapters are made with Female Thread for Increased I. P., Water Works Standard or Lead Flange.



To use standard Corporation Stops with Increased I. P. or Water Works Standard Thread, and where a direct connection of the Corporation Stop and Copper Pipe is desired, the above stop has been designed. (See cut above for sectional view of joint.) These stops permit a Hays 90° seal with the use of regular male mandrels.

Write for complete details of

The Hays Copper Plumbing Method for Water Works and House Plumbing

Hays Manufacturing Co. Erie, Pa.

UNDER GROUND— OR ABOVE

When pipe resists all five of the major forces that tend to lower pipe endurance, it's bound to be good. That's what Reading 5-Point Pipe does —and that's why Reading 5-Point Pipe effects such remarkable economies in water works service!

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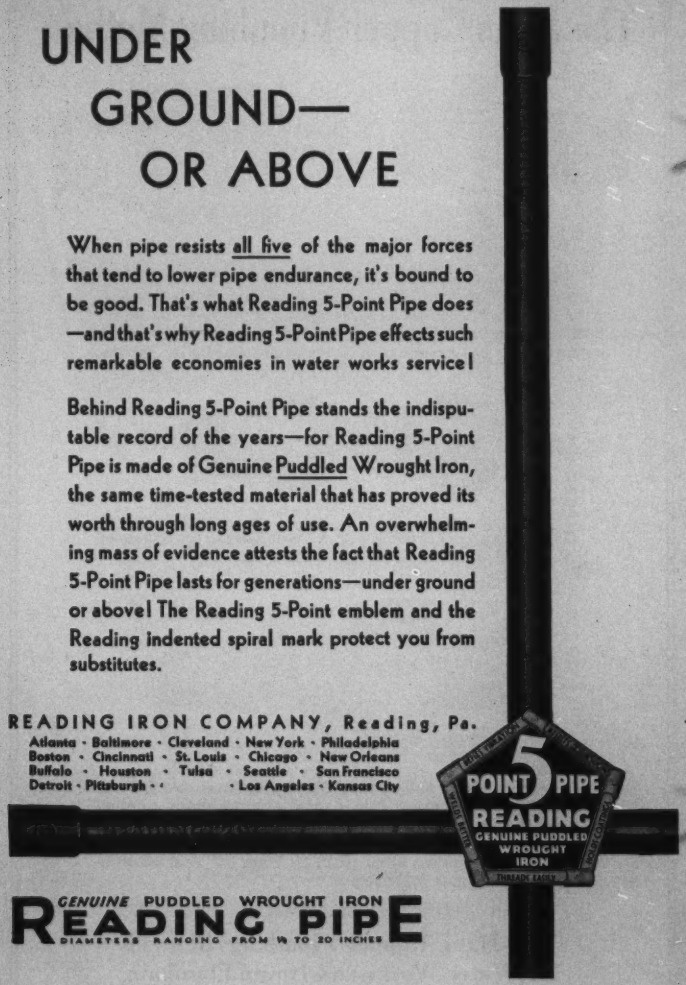

GENUINE PUDDLED WROUGHT IRON
READING PIPE
DIAMETERS RANGING FROM ¼ TO 20 INCHES

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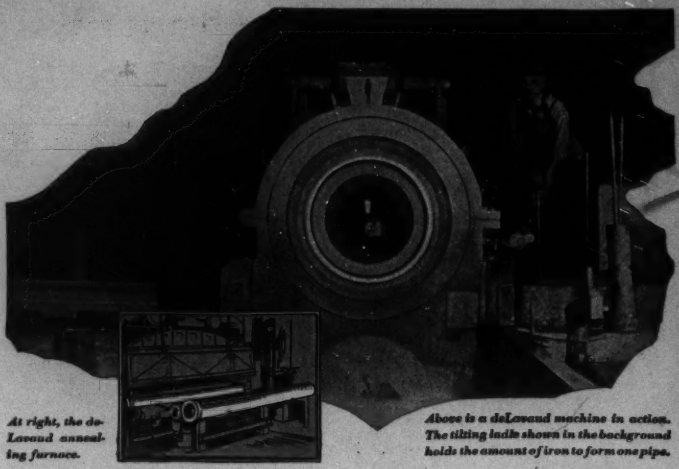

At right, the deLavaud annealing furnace.

Above is a deLavaud machine in action. The tilting ladle shown in the background holds the amount of iron to form one pipe.

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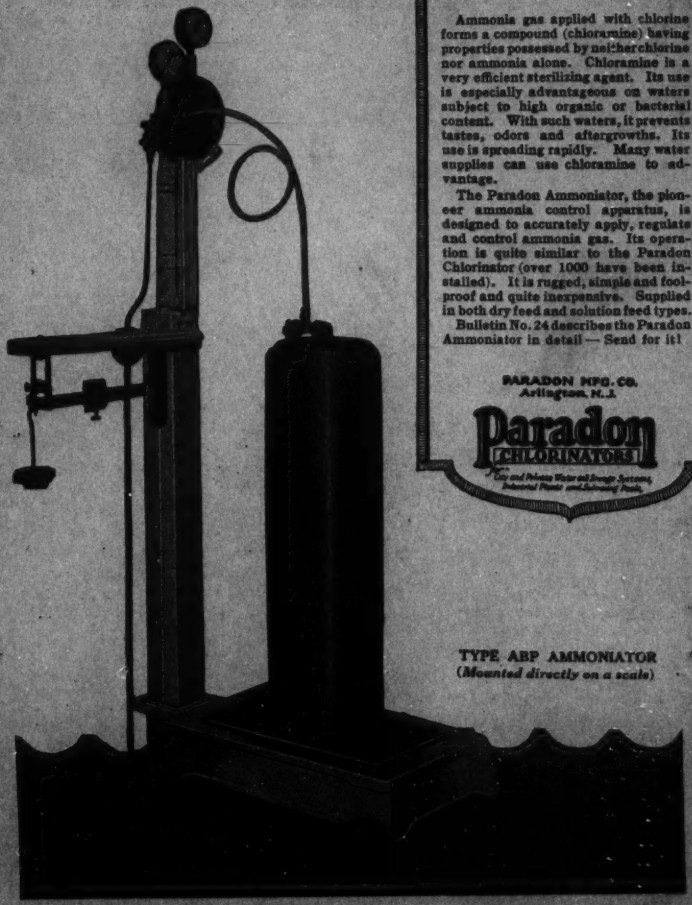

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